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**EFFECTS OF A 50 HZ MAGNETIC FIELD ON HUMAN  
VISUAL DURATION DISCRIMINATION  
AND RECOGNITION MEMORY**

A thesis presented in partial fulfilment  
of the requirements for the degree  
of Master of Arts in Psychology  
at Massey University

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## ABSTRACT

The purpose of this study was to investigate the direct and delayed effects of a sinusoidal 100  $\mu\text{T}$ , 50 Hz intermittent magnetic field on human performance measures. Eighty participants (aged 19-53) completed the experiment which involved a visual duration discrimination task and a recognition memory task. Initially all participants completed the study phase of the recognition memory task in which 40 abstract shapes were presented in a random order. A two alternative forced choice visual duration discrimination task followed in which participants had to decide which of two consecutive light flashes was longer in duration. The duration discrimination task had only one hard level of difficulty over the 200 trials with a standard flash duration of 50 ms paired with an alternative hard flash duration of 65 ms. During the duration discrimination task, 40 participants were sham exposed while the remaining 40 were exposed to a 100  $\mu\text{T}$ , 50 Hz magnetic field. Participants were randomly assigned to either the sham or exposure groups and the study was conducted under double-blind procedures. Reaction time and percentage of correct decisions were recorded during a total exposure time lasting approximately 11 minutes. The two alternative forced choice recognition memory testing phase was then conducted in which participants viewed 40 pairs of abstract shapes, each pair presented for six seconds. Participants had to decide which of the two shapes (left or right) they had previously seen during the study phase. In addition, participants had to rate their confidence in each of the 40 decisions on a four point rating scale (1 = very sure to 4 = unsure). Both percentage of correct decisions and confidence ratings were recorded for each participant. Participants were only exposed to the magnetic field during the visual duration discrimination task. The results of an earlier investigation were unsupported as the present results found no field-effects between sham and exposure groups on both measures of reaction time and percentage of correct decisions during the visual duration discrimination task. However, a reduction in the percentage of correct decisions and confidence during the recognition memory task was observed for participants who had been previously exposed to a magnetic field. Differences in experimental parameters and insufficient power render comparisons with other human magnetic field studies impossible. The need for exact replication studies with maximum design sensitivity was discussed within the context of a research field that is to produce small effect sizes.

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## INTRODUCTION

### *Overview*

Electricity is ubiquitous. Over the past century the transmission and distribution of electricity has increased to such proportions that it is impossible in Western cultures to avoid exposure to electric and magnetic fields. Many systems and devices have been invented for human use in everyday environments and our dependence on electricity as a main source of energy is unquestionable. As a consequence of this increased distribution and use, we are often exposed to extremely low frequency (ELF) magnetic fields (MFs) generated by an alternating mains current. Generally, ELF field exposure is experienced through transmission line power frequencies of 50 or 60 Hz (New Zealand - 50 Hz, USA - 60 Hz). A vast range of appliances we have come to depend on generate these MFs including computers, toasters, microwaves, electric heaters, televisions, radios, and electric lights.

Early research discovered that electric and magnetic fields may have effects on biological systems (Gamberale, 1990). There is now a very large amount of literature reporting on the effects of electromagnetic fields (EMFs) on non-human cell lines and live animals (e.g., see National Research Council [NRC], 1997 for a review). Research on the effects of EMFs on humans has followed two main directions, epidemiological studies and human behaviour studies. Epidemiological studies have focused on

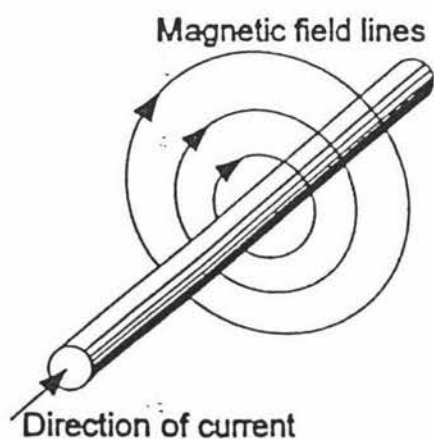
associations between magnetic field exposure and health risks. Kavet (1996) states that studies have reported modest associations between EMF exposure and cancer of several types. Reviews by Wood (1993) and the National Radiological Protection Board (NRPB, 1992) support the idea that exposure to ELF magnetic fields may effect biological systems and that further investigations in this field are indeed warranted. Results regarding the effects of ELF field exposure on health remain inconclusive while public concern continues to grow. Undoubtedly, this is a controversial and interesting research area which has grown rapidly over the past decade, and continues to do so.

In comparison, research regarding the possible effects of MFs on human behaviour has been limited. Some evidence has been gathered suggesting field-induced effects on performance (Cook, Graham, H. D. Cohen, & Gerkovich, 1992; Graham, Cook, H. D. Cohen, & Gerkovich, 1994; Whittington, Podd, & Rapley, 1996) but comparisons across studies are difficult to make owing to differences in experimental design, magnetic field intensities and frequencies. Also, Whittington and Podd (1996) identified that to date research has generally shown insufficient statistical power to detect field-related effects when they do exist. The present study was partly designed to address the latter issue and to reproduce in part the results obtained by Whittington et al. (1996) in an investigation of a 50 Hz magnetic field on visual duration discrimination. In addition, the study provided an opportunity to investigate the delayed effects of a 50 Hz magnetic field on human recognition memory.

## *Magnetic Fields*

Confusion can arise when discussing electric and MFs. Electric fields are reasonably constant, can be easily shielded and only induce weak currents in the body. In comparison, MFs can only occur when an electrical current is moving through a conductor, can not be easily shielded against and can induce electrical currents throughout the body (NRC, 1997; Sagan, 1996).

A magnetic field is produced when an electric current passes through a conductor. The MF moves out from the conductor and surrounds the conductor, the direction of the magnetic lines of force running counterclockwise when observed in the direction in which the electrons are moving (see Figure 1).



*Figure 1.* Magnetic field surrounding a current-carrying conductor

The two most common measurement units used when talking about MFs are Tesla (T) and Gauss(G) (Sagan, 1996). Tesla and Gauss are directly related as  $1.0 \text{ T} = 10\,000 \text{ G}$  (Koch, Koch, Martin, & Moses, 1993; National Radiation Laboratory [NRL], 1996).

The present study will adhere to the International System of Units (SI). Magnetic field strength (H), measured in amperes per metre (A/m), will be referred to in microtesla ( $\mu\text{T}$ ). Microtesla represents magnetic flux density (B) which is a common descriptor of MFs (Nelson, 1996). Magnetic fields of 30 Hz or below are sometimes referred to as sub-extremely low frequencies. However, the most commonly used term is extremely low frequency (ELF); ELF MFs range from DC to 300 Hz.

Important factors contributing to MF strength include the magnitude of the electric current and the distance from the MF source. As the magnitude of the electric current increases, the MF also increases. Meanwhile, an inverse relationship exists between MF strength and distance from the source. As the distance from the electric current-carrying device increases, the MF strength decreases (Tenforde, 1986; Tenforde & Kaune, 1987).

### *Living with Magnetic Fields*

MFs are present in nearly every civilized Western environment. Natural MFs are produced by the earth's magnetic force and can also be observed in phenomena such as solar activity and thunderstorms. The earth's nearly constant MF is approximated at  $50 \mu\text{T}$  (NRL, 1996), while the average level of MF present in an house or workplace is

considerably lower. An extensive Electric Power Research Institute (EPRI) study (1993; cited in NRC, 1997) measured the MF in the center of rooms from 992 houses. The average MF across all rooms in each house ranged from 0.01 to 0.3  $\mu\text{T}$  (NRC, 1997).

Transmission lines produce some of the largest manmade MFs outside the laboratory. In New Zealand the MF under a high voltage transmission line can reach up to 5  $\mu\text{T}$  while the MF under low voltage lines, such as overhead street cables, can reach up to 1.5  $\mu\text{T}$ . Distance from the line can reduce exposure levels greatly. For example, a distance between 50-100 m from a power line will reduce MF levels to that which are normally found in houses (NRL, 1996).

Domestic homes contain a vast array of electrical appliances that can vary greatly in the MF that they produce. Appliances which produce the highest MFs are generally those with electric motors such as hair dryers, can openers and food processors. Close contact with such appliances can, in some cases, expose a person to higher levels of MF than would be experienced under a power line (NRL, 1996; Sagan, 1996). Table 1 shows the MF levels of a variety of common household appliances.

As human exposure to MFs increased over the years so, too, did the demands for a set of limits that would provide reasonable control and safety for the general public. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) developed a

set of exposure guidelines regarding 50/60 Hz electric and MFs in 1993. These guidelines were based on research and the notion that manmade electric and MF

**Table 1**

Examples of common appliances and the magnetic field strengths that people are exposed to at two different distances from the source.

Sources	Magnetic Field ( $\mu\text{T}$ ) at 0.15 m	Magnetic Field ( $\mu\text{T}$ ) at 0.3m
<i>Domestic sources</i>		
Blenders	3-10	0.5-2
Can openers	50-150	4-30
Coffee machines	0.4-1	Bkg <sup>a</sup> to 0.1
Clothes dryers	0.2-1	Bkg to 0.3
Clothes washer	0.4-10	0.1-3
Dishwashers	1-10	0.6-3
Electric ovens	0.4-2	0.1-0.5
Electric shavers	0.4-60	Bkg to 10
Hair dryers	0.1-70	Bkg to 7
Irons	0.6-2	0.1-0.3
Microwave ovens	10-30	0.1-20
Refrigerators	Bkg to 4	Bkg to 2
Toasters	0.5-2	Bkg to 0.7
Vacuum cleaners	10-70	2-20
<i>Work related sources</i>		
Battery chargers	0.3-5	0.2-0.4
Electric drills	10-20	2-4
Fax machines	0.4-0.9	Bkg to 0.2
Fluorescent lights	2-10	Bkg to 3
Photocopiers	0.4-20	0.2-4
Power saws	5-100	0.9-30
Video-display terminals	0.7-2	0.2-0.6

*Note.* Based on Table 2-3 in National Research Council (1997, p.30). <sup>a</sup>Bkg represents background levels of MFs. The lowest level of the MF produced by the appliance could not be detected above background levels of MFs.

exposure levels should not exceed those produced naturally within the human body.

New Zealand exposure guidelines are equal to or more conservative than exposure guidelines of other countries (NRL, 1996; see Table 2).

**Table 2**

Limits of exposure to 50/60 Hz electric and magnetic fields.

<b>Exposure characteristics</b>	<b>Electric field strength kV/m (rms)<sup>a</sup></b>	<b>Magnetic flux density microtesla (rms)</b>
<i>Occupational</i>		
Whole working day	10	500
Short term	30	5,000
For limbs	-	25,000
<i>General public</i>		
Up to 24 hours per day	5	100
Few hours per day	10	1,000

*Note.* From Electric and magnetic fields and your health. (p. 9), by National Radiation Laboratory Ministry of Health, 1996, Christchurch, New Zealand.

<sup>a</sup>rms: root-mean-square.

### *Epidemiology*

Public concern regarding human exposure to MFs has resulted in an increase in epidemiological research. Over the past 15 years residential and occupational studies have attempted to establish a link between EMF exposure and a number of different cancers. Power transmission lines and the accurate measurement of the MFs that they produce has provided researchers with an opportunity to explore possible effects. As a



result, weak correlations have been reported between distribution lines and childhood leukemia (Feychting & Alhbom, 1993; London, Thomas, Bowman, Sobel, Cheng, & Peters, 1991; Savitz & Chen, 1990; Tomenius, 1986; Wertheimer & Leeper, 1979).

Different forms of leukemia (acute myeloid and chronic lymphocytic) have been weakly associated with electrical workers who are generally exposed to higher than normal EMFs. In addition, a greater risk for brain and breast cancer in this population has been suggested (Demers, Thomas, Rosenblatt, & Jimenez, 1991; NRPB, 1992; Savitz & Loomis, 1995). A recent review (Kavet, 1996) presents key epidemiological studies but questions the conclusiveness of the combined results due to inconsistencies, design problems and insufficient evidence.

Despite the suggestive nature of these results, more research is required before investigators are able to reliably conclude that EMFs are a human carcinogen (Kavet, 1996; Vistnes, Ramberg, Bjornevik, Tynes, & Haldorsen, 1997). Little hard evidence has been produced to support such epidemiological claims and without further scientific inquiries we run the risk of raising public concern to a high level, based on research which is still very much exploratory (NRC, 1997).

Epidemiological studies are, however, very topical at the present time owing to very real human concerns. People can relate to discussions about the association between power lines and childhood cancer much more readily than to discussions about exposure effects

on a simple performance task or on endocrine responses. Is public concern justified and well-informed, or has it been built on myth and hysteria?

Lay understanding of low-frequency electric and magnetic fields has been investigated (Morgan, Florig, Nair, Cortes, Marsh, & Pavlosky, 1990). Results indicated that while misunderstanding is generally widespread amongst lay people, this misunderstanding is limited. Most participants responded inaccurately but in the right direction and thus their confused knowledge was predicted as being easily corrected by simple methods. Interestingly, while better educated people did display greater understanding of ELF MFs, they also tended to be overly confident about their responses. The implication is that simple interventions to improve lay understanding of ELF MFs would be of great benefit to enhance the accuracy of public awareness (Morgan et al., 1990).

A major problem in establishing a link between ELF MFs and human health for both laypeople and scientists alike is that the mechanism by which weak ELF MFs affect biological systems is far from understood. How can such low level, low frequency radiation bring about changes in such systems? This question is addressed in the following section.

### ***Biological Mechanisms of Interaction***

The mechanism through which MFs interact with biological systems continues to elude researchers. While many researchers strive to establish a mechanism through which

tissues or cells are altered by MFs, many question whether such a mechanism exists (Adair, 1991; Bennett, 1994). The debate stems from the fact that the human body is an electrically noisy place. Internal activity is generally stronger than external EMFs; therefore, it is argued, there is little possibility of weaker external EMFs being detected or having any affect over the stronger internal "noise" (NRC, 1997; Sagan, 1996).

Biological effects of ELF exposure have, however, been reported in many studies (Graham & H. D. Cohen, 1985; Lyskov, Juutilainen, Jousmaki, Partanen, Medvedev, & Hanninen, 1993) and there is growing agreement that MFs do affect biological systems. A popular theory regarding performance effects is that MFs bring about changes at a cellular level with interaction most likely occurring in the brain and central nervous system (H. D. Cohen, Graham, Cook, & Phelps, 1992; Lednev, 1991; Polk, 1991; Sagan, 1996). A number of different biological effects has given rise to the belief that more than one mechanism of interaction exists (Graham et al., 1994; Wilson, Hansen, & Davis, 1994). For example, Sagan (1996) identifies and summarizes four main explanatory theories of EMF interaction: induced currents, transients, effects of magnetite and resonance. Electrical currents are induced in human tissue when a person is exposed to a moving MF. However, known biological effects (such as phosphenes and muscle stimulation) require electrical currents far larger than those produced by exposure to normal power sources. Therefore, "induced currents" is not considered a plausible mechanism for interaction. The transient theory is based on sudden changes in the MF level that can produce higher levels of induced currents than normally present in the human body. Transients occur frequently in our environment and may be

responsible for biological effects. Magnetite is a mineral containing small magnets which are known to move when exposed to an ambient MF. Non-human species such as bacteria, fish, honeybees and birds use the mineral for navigational purposes but whether or not magnetite exists in human bodies and the function that the mineral has is still uncertain.

The parametric resonance model is one possible mechanism that has received much attention (Blackman, Blanchard, Benane, & House, 1994; Blanchard & Blackman, 1994). Built originally from the works of Podgoretskii and Dhrustalev (1964; cited in Trillo, Ubeda, Blanchard, House, & Blackman, 1996) it is based on the possible resonant interaction between applied MF and biological systems. Lednev (1991) applied the theory to biological systems and debate continues regarding its application. The fundamental principle underlying the model is that certain ionic changes occur due to a MF modulated at a specific frequency. The vibrational energy state of the ion is lowered and the binding between the protein and ion is strengthened, causing the protein to continue with its ion-dependent response. Calcium ions have been the focus of attention but the involvement of other ions is conceivable. Set parameters are required for the “protein binding” effect to take place, including “the presence of a static magnetic field (comparable with the geomagnetic field) modulated by a parallel alternating field of similar amplitude” and of a specific frequency (Male, 1992, p. 87). While many positive practical implications of the model are outlined by Male (1992), further research is required to test the theory further.

A popular theory regarding performance effects is that MFs effect changes at a cellular level with interaction most likely occurring in the brain and central nervous system (H. D. Cohen et al., 1992; Lednev, 1991; NRC, 1997; Polk, 1991; Sagan, 1996).

Discovering a mechanism of interaction is an essential element in accurately understanding the effects that MFs have on humans. While current theories are interesting and plausible, no one particular theory of how ELF MFs (less than 100  $\mu$ T) can affect biological systems has received clear and unequivocal support.

The search for a mechanism of interaction continues and each new study expands our knowledge a little further. Studies that have contributed a great deal to the understanding of MFs on biological systems are those conducted on animals.

### *Animal Studies*

Valuable information can be gained from animal experimentation especially in cases where the use of human participants would be unacceptable (Weiten, 1995). Studies exposing animals to MFs have shown effects at the behavioural, chemical and physiological levels (Libroff, Thomas, & Schrot, 1989; Ossenkopp & Cain, 1988; Thomas, Schrot, & Libroff, 1986; all cited in NRC, 1997). Numerous animal studies have been carried out and a recent review (NRC, 1997) focused on three main areas of interest: carcinogenesis, reproduction and development, and neurobehavioural and neuroendocrine responses. The review concludes that no clear link between MF

exposure and cancer has been found, that MF exposure has produced no significantly adverse effects on reproduction, development or neurobehavioural responses in animals, and that although changes in neuroendocrine responses have been reported, no negative health effects have been observed (NRC, 1997).

While the review based its summary on an overall view of animal studies, consideration of individual animal studies presents a different perspective. Many animal studies have, over the years, reported biological effects of EMFs. In addition, research has shown interactions of EMF with cells, tissues, organs, and embryonic development (Espinar, Piera, Carmona, & Guerrero, 1997). Carcinogenic effects have also been reported in a number of animal studies (McLean, Stuchly, Mitchel, Wilkinson, Yang, Goddard, Lecuyer, Schunk, Callary, & Morrison, 1991; Mevissen, Stamm, Buntenkotter, Zwingelberg, Wahnschaffe, & Löscher, 1993), and MF exposure has been found to inhibit night time pineal and blood melatonin levels in animals exposed to MFs ranging from 19  $\mu$ T - 5.2  $\mu$ T (Kato, Honma, Shigemitsu, & Shiga, 1993; NRC, 1997). It has been suggested that this observed suppression of melatonin may be a possible biological mechanism through which the risk of cancer is increased (Graham, Cook, Riffle, Gerkovich, & H. D. Cohen, 1996).

It remains unclear whether animals can detect 60 Hz MFs but even if they could, as suggested for rats in higher exposure levels (3 mT at 60 Hz), no indication of an effect has been found. No avoidance behaviour or negative health effects were produced by Lovely, Creim, Kaune, Miller, Phillips, and Anderson (1992). The vast range of

different results obtained from animal investigations probably can be attributed to the varied animal models and parameters of exposure fields used in each study. Accurate and precise replication studies and meta-analyses are required before clear connections can be made.

An obvious difference that highlights the need for caution when considering animal results in relation to humans is that the physiological make up of animals is in most cases different to humans. The example of a rat body being far smaller than a human head or chest illustrates this point perfectly. Animal studies are extremely important but validly comparing human effects with that of animals is often not plausible (H. D. Cohen et al., 1992). As a result, a number of investigations have examined the effect of ELF MFs on human physiology and performance.

### *Human Studies*

Although the demand for studies investigating the effects of MFs on humans is great, there are a very limited number available. One of the earliest known experiments to be carried out on human performance was conducted by Friedman, Becker, and Bachman (1967). Their study found a direct effect on simple reaction time (RT) which occurred in a near DC field, just 0.2 Hz. Twelve men each completed a psychomotor task under three conditions; sham (no field), 0.1 Hz, and 0.2 Hz. No effect was found in the 0.1 Hz exposure group but the 0.2 Hz exposure group showed a significant increase in RTs.

The observed effect was later replicated by Friedman et al. (1967) with 12 female participants.

The first genuine attempt to fully replicate Friedman et al.'s (1967) study was not carried out for almost 30 years (Podd, Whittington, Barnes, Page, & Rapley, 1995). Podd et al. adhered closely to Friedman et al.'s design making some adjustments to improve design sensitivity. Identified methodological problems in the Friedman et al. study included the small number of practice trials (5) and the relatively long trial durations (5 seconds each). Podd et al. increased the number of practice trials to 50 and individual trial duration was reduced to 2 seconds. Total MF exposure time was held reasonably constant due to the increased number of experimental trials. In addition, median RTs were based on 30 trials in comparison to Friedman et al.'s median RTs which were based on only 10 trials. A within-subject design was used with 1.1 mT field strength. Each of 12 participants were exposed for five minutes under each condition (sham, 0.1 Hz, 0.2 Hz) over three consecutive days.

A second study was included which used 24 participants who were only exposed to the 0.2 Hz field strength. In order to maximize the chances of detecting any possible effects the predictions of parametric resonance theory (Male, 1992) were applied in the second study. Frequency, flux density and field orientation were all set accordingly. The results failed to replicate those found by Friedman et al. (1967) and the parametric resonance theory was unsupported in its first application to human behaviour. However, Podd et al. (1995) emphasized the need to increase statistical power in future research if there is



to be a reasonable chance of detecting weak MF effects, or replicating the findings of previous research.

Two earlier human studies were reported in a review by Gamberale (1990). A Swedish study found no effect on RT or other performance measures when the exposure intensity level was 50 Hz, 0.3 mT (Johansson, Lundquist, Lundquist, & Scuka, 1973; cited in Gamberale, 1990). It was suggested that the order in which participants receive the real exposure and sham exposure conditions may have affected the outcome (Johansson et al., 1973; Stollery, 1986). More often than not, measures of human performance are combined with measures of human physiology such as heart rate, blood pressure and so on. A later study, involving participants who were exposed for 4 hours daily for one week in a 5 mT field, showed no effect on performance in psychomotor tasks. A number of physiological measures such as blood pressure, body temperature, EEGs, and electrocardiograms also showed no effect (Sander, Brinkmann, & Kuhne, 1982; cited in Gamberale, 1990).

A Russian experiment (Lyskov et al., 1993) used 20 participants exposed to 1000 A/m (1026  $\mu$ T) field strengths in 1-hr sessions to measure EEG, omega potentials and RT. Ten participants were continuously exposed to a sinusoidal 45 Hz MF while 10 were intermittently exposed. Each participant completed one sham and one real exposure session in a counterbalanced order and measures were taken before and after exposure. No significant effect was found for RT but, interestingly, those who completed the real exposure first showed a marked decrement in learning when compared to those who

were sham exposed first. Significant results were obtained mainly after intermittent exposure. The EEG reading showed an increase in alpha activity, a decrease in delta activity, an increase in beta waves, and an overall increase in power in the occipital derivations after MF exposure. The study provided support for the notion that MF exposure can have an effect on human brain functioning, but further investigation and replication are required before clear interpretations can be made.

A prominent contributor to the MF research field is the Midwest Research Institute (MRI) which is located in the United States of America. It was the challenge of conducting human ELF research under controlled double-blind conditions that prompted the MRI to not only complete a field perception study but also to build an ELF exposure facility in which further human testing could be carried out. It became one of the first facilities to be developed which provides a relatively safe, controlled environment for testing of human exposure. The facility was designed to control humidity and temperature while maintaining a double-blind procedure. Physiological data collection before, during and after exposure is possible and continuous or intermittent exposure can be achieved. Uniform, corona-free 60 Hz electric (0 to 16 kV/m) and magnetic (0 to 32 A/m,  $B = 0$  to 40  $\mu$ T) fields are generated for exposure purposes (H. D. Cohen et al., 1992).

The MRI has conducted a number of studies over the years, investigating the effects of 60 Hz electric and magnetic fields on human physiology and performance. The first study exposed 12 men to a field strength of 9 kV/m, 20  $\mu$ T (Graham, H. D. Cohen,

Cook, Phelps, Gerkovich, & Fotopoulos, 1987; cited in Cook et al., 1992). Exposure consisted of two 3-hr blocks daily over four days. Two days involved real exposure while two days involved sham exposure in a counterbalanced order. Double-blind procedures were adhered to and each man acted as his own control. Results showed a slowing in heart rate, changes in event-related brain potentials, elevated levels of dopamine in urine and improved performance on a choice reaction time task. The credibility of some (nonsignificant) outcomes was hindered by the low number of participants hence, low statistical power.

Maresh, Cook, H. D. Cohen, Graham, & Gunn (1988) conducted the second double-blind study. The same field strength was maintained (9 kV/m, 20  $\mu$ T) and 11 participants completed four 2-hr exposure sessions. Two sessions were sham exposed and two sessions were field exposed in a counterbalanced order. Exercise and resting conditions were also included and a slowing in heart rate was observed under resting conditions.

A follow-up study (Cook et al., 1992; Graham et al., 1990) set out to support the screening study by reproducing and adding to the initial results. They carried out an extensive replication study investigating the effects of 60 Hz MFs and electric fields on human neurobehavioural measures. The double-blind study included 30 men who were randomly assigned to two groups. Group 1 contained 18 men who participated in one 6-hr exposure session every week for four weeks. Nine of these participants were exposed in the order of sham-field-field-sham, while the remaining nine participants

were exposed in the order of field-sham-sham-field. Group 2 contained 12 men who also participated in one 6-hr exposure session every week for four weeks. Half of the participants were sham exposed in every session while the other half were exposed to the field in every session. Thus, Group 1 used a repeated measures design while Group 2 used a between-participants design. A number of different variables were measured during and after exposure. Performance was enhanced by the electric/magnetic fields for a choice reaction time task. The EMFs also slowed heart rate replicating the earlier screening study results. Event-related potentials were affected for the P300 and a decrease in the auditory P300 amplitude was observed after exposure. Interestingly, physiological effects were maximized immediately after the field had been switched on or off.

The MRI conducted a fourth double-blind study to replicate the results of the initial three studies (Graham et al., 1990). Twenty-eight participants were randomly assigned to either a sham or field exposure condition in a between-subjects design. In order to increase any physiological effects, the field strength was increased from 9kV/m, 20  $\mu$ T to 12 kV/m, 30  $\mu$ T. Surprisingly, none of the physiological effects previously reported were observed.

These results prompted the MRI to conduct a double-blind study investigating the dose-response relationship between humans and EMFs (Graham et al., 1994). Three groups of 18 men were assigned to one of three field exposure levels - low group: 6 kV/m, 10  $\mu$ T; medium group: 9 kV/m, 20  $\mu$ T; high group: 12 kV/m, 30  $\mu$ T. Each participant

completed one 6-hr sham exposure session and one 6-hr field exposure session (the field exposure level set according to their allocated group). RT and performance accuracy on a time estimation task were significantly poorer in the low level group only, and the slower RTs were only observed after real exposure. Significant slowing of heart rate and changes in the latency and amplitude of event-related potentials were present in the medium-level group. These results suggest that the relationship between exposure field strength and effect is not linear. Also, the level of field exposure that produces an effect may depend on what is being measured. That is, field exposure levels that induce an effect may differ for different endpoints.

The effects of EMFs on time-related variables have produced inconsistent results. Slower RT and increased errors were reported in workers exposed for five days to 7-10 kV/m, 50 Hz fields (Sazanova, 1967, cited in Cook et al., 1992). In another study, participants showed faster RTs when exposed to 1 and 15 kV/m, 50 Hz fields (Hauf, 1976, cited in Cook et al., 1992) but later attempts failed to replicate these findings (Eisemann, 1976; Rupelius, 1976; both cited in Cook et al., 1992).

Earlier studies reporting results on time-related tasks have interpreted improved performance in terms of field-induced excitation or reduced performance as field-induced fatigue (Cook et al., 1992). As Whittington et al. (1996) point out, this issue can not be resolved until research includes measures of performance before, during and after exposure.

Unfortunately, studies that have varied task difficulty and reported enhanced performance when exposed to a MF have varied the task difficulty by completely changing the task itself. Ideally the task should remain the same but with varying levels of difficulty. One study that held the task constant while varying difficulty level found a decrease in RT only at the most difficult level of the task when exposed to a 50 Hz, 100  $\mu$ T intermittent (1s on, 1s off) MF (Whittington et al., 1996). Ninety-seven participants completed both field exposure and sham conditions. Each exposure session was approximately nine minutes long containing 150 trials; full double-blind procedures were maintained. On every trial a light emitting diode (LED) displayed two flashes. Participants were asked to indicate which of the two consecutive flashes was longer in duration on a two-key response pad. Three levels of difficulty were included in this visual discrimination task. A standard duration of 50ms was maintained while comparison stimuli were 65, 100 or 125ms. All sessions were counterbalanced and measures included RT, percentage of correct decisions, heart rate, and blood pressure before and after exposure. The detection of statistically significant field effects was attributed to the high level of statistical power used. To achieve a higher than usual level of statistical power, a number of different techniques were utilized. A large number of participants were used, the alpha level was relaxed from 0.05 to 0.30, intermittent exposure was used (one second on, one second off), and the applied MF was aligned with the geomagnetic field as dictated by the parametric resonance theory (Whittington et al., 1996). A significant reduction in RT was observed for only the most difficult level of the task with a 14ms improvement in RT in the field condition. No effect was reported for the intermediate or easy levels of the task or for cardiovascular

performance. Although percentage of correct responses slightly declined as RT grew faster, no statistically significant effects were noted. That an effect was reported after only nine minutes of exposure suggests that lengthy exposure periods are not necessary for an affect to occur. Whittington et al. identified exposure duration as a possible critical factor in understanding MFs and put out a call for further investigation of this variable.

The possibility that a speed accuracy trade-off may have been partly responsible for the observed results in the Whittington et al. (1996) study prompted Kazantzis, Podd, and Whittington (in press) to conduct a partial replication investigation. Ninety-nine participants completed two blocks of trials under double-blind conditions with each block consisting of 150 visual duration discrimination trials. Participants were exposed to a 50 Hz, 100  $\mu$ T MF in one block and sham exposed in the other block, blocks being presented in a counterbalanced order. On each trial, participants viewed a standard light flash of 50 ms paired with another light flash of 60, 100 or 125 ms. As with the Whittington et al. (1996) study, participants were required to indicate on a response pad which of the two flashes was the longer in duration. Time-of-day effects were also investigated and participants were randomly assigned to either a morning or afternoon session. Results showed small but a statistically significant ( $\alpha = 0.3$ ) increase (1.6%) in performance accuracy but only at the most difficult task level under field exposure conditions. The results suggested that females were more affected than males. No time of day effects were reported with no significant differences between sham and MF conditions or time of exposure.

Thirty years have passed since the first study investigating MF related human performance effects was published (Friedman et al., 1967) and still no conclusive evidence has been found. The ambiguity evident throughout the human MF research arena can be attributed in part to the varying experimental field parameters present in different studies. Without precise replication studies little hope can be held of building up a useful knowledge base from which to work from.

Complexities also arise from the fact that MF effects appear to be extremely sensitive to slight changes and thus it is difficult to pinpoint a reliable performance measure. In addition, there is a seemingly infinite number of possible performance measures that may be affected by MF exposure of which only a few have been tested. While it is inconceivable to entertain the notion of exhausting all of the possibilities through individual research, a more logical suggestion is to investigate those performance measures that have the greatest impact on our lives, such as memory functioning.

### *Recognition Memory*

Recognition is a crucial component of memory that humans rely on and use everyday. Without it the ability to function at an acceptable level would be lost and simple tasks such as recognizing a familiar face or a favourite piece of music would be impossible (Matlin, 1989; Parkin, 1993). Recognition involves judging whether a stimulus has been encountered previously. In an experimental setting, recognition testing involves two



stages. Initially a stimulus is presented and the participant is asked to remember it. At a later time the target stimulus is presented alone or with one or more other similar stimuli. In the former situation the participant is simply asked to judge with a yes/no response whether the stimulus was previously experienced. In the latter, more commonly used situation, the participant is engaged in an alternative forced-choice decision. That is, he or she must choose from an array of items (can be two or more) which one is the target stimulus (Brown, 1976; Parkin, 1993).

Such a decision is based on the participant's ability to discriminate between the target stimulus and distractor items. Distractors can range from being very similar to dissimilar from the target stimulus. Studies have found that recognition performance is more accurate and faster when distractors are dissimilar to the target (Baddeley, 1997). In addition, research has found that recognition performance accuracy decreases as the number of distractors increases (Podd, 1990). It has been argued that the conception of recognition used in experimental study is really recognition-discrimination memory. This differs greatly from the layman's conception of recognition which means simply to identify what has been seen before (Cooper & Monk, 1976; Wallace, 1980). The present study, however, uses the simple term recognition to represent the experimental concept.

When discussing recognition it is necessary to define recall to prevent confusion between the two. The main difference is that recognition provides assistance through

cues while recall generally does not involve assistance at all. Like recognition, recall requires that the participant attempt to remember the target stimulus. However, when tested the participant must generate the target stimulus without any cues (Brown, 1976; Parkin, 1993). For example, if the target item was a picture the participant may be asked to describe or draw it.

Many theories of recognition have been developed and for years it was commonly thought that recognition was a single process. Two popular theories of retrieval that subscribe to this belief are generation-recognition models and the encoding specificity principle (Parkin, 1993). Generation-recognition models propose that recall involves two stages, generation and recognition of the target stimulus, while recognition involves only the recognition stage. A well known generation-recognition model developed by Kintsch (1970) proposes that when a stimulus is presented to be remembered, an occurrence marker is attached to the node that represents the item in memory. Testing involves the generation of a number of possible target items followed by a search for the occurrence marker. When the marker is found, recognition occurs and the retrieval process is complete. The appeal of a generation-recognition model was strengthened through its ability to account for many findings that have been discovered differentiating recall and recognition. Such findings include the fact that retrieval performance is generally better for recognition as only one process is involved compared to the two stages required for recognition, and recall is better for words that are commonly encountered in the English language while recognition is better for words that are used less (Parkin, 1993).

During the 1970's many experiments were carried out to test the generation-recognition theory resulting in a number of studies that failed to support the model (Flexser & Tulving, 1978). These findings prompted Tulving and Thomson (1973) to develop a new theory named the encoding specificity principle. Under this theory, the retrieval process involved in recall and recognition is the same. Initially, key features are encoded in memory and when tested, retrieval depends upon the interaction between the information provided by a recognition probe or cue (retrieval environment) and the memory trace. Recognition or recall occurs if the overlap between the retrieval environment and the memory trace reaches a sufficient level. Like the generation-recognition theory, the encoding specificity principle accounts for the performance differences between recall and recognition as stated previously. Additional support for the encoding specificity principle came from many studies that produced recognition failing results, thus undermining the generation retrieval model. However, a weakness of the theory is that it is not empirically testable (Baddeley, 1997).

While the debate between whether generation-retrieval theory or the encoding specificity theory is correct continues, research has found that recognition can involve two processes. The two stages of recognition presented by the dual-process theory are the initial familiarity response and the context retrieval stage (Parkin, 1993). Under this approach recognition can be either context free or context dependent with recognition based solely on familiarity or on both familiarity and context. Evidence has provided support for the dual-process theory and the proposed separable familiarity and context-dependent aspects of recognition (Huppert & Piercy, 1978; Mandler & Boeck, 1974).

Johnston, Dark, and Jacoby (1985) conducted experiments to explain how these two facets of recognition operate. Results provided support for the theory that familiarity is based on perceptual fluency (the ability to identify a stimulus more quickly because it has been experienced previously) while context retrieval is a search process.

Perception involves the interpretation of sensory stimuli and one process that is crucial to the perception of visual stimuli is pattern recognition. "Pattern recognition involves the identification of a complex arrangement of sensory stimuli" (Matlin, 1989, p. 23). Identifying a face, a shape or a letter of the English language are all examples of pattern recognition that we rely on everyday. Over the years, researchers have attempted to uncover the processes involved in pattern recognition and Matlin (1989) outlines four theories including template-matching, prototype models, distinctive features models and the scene-analysis approach. The template-matching theory proposes that a stimulus is compared with templates (a specific patterns) stored in memory and recognition occurs when a match is made. However, the theory is considered inadequate due to inflexibility as the template must match the stimulus exactly before recognition can occur. Under such circumstances, a template would have to exist for every item and its variation which is logically impossible. The prototype model extended the template theory incorporating flexibility. Prototypes are stored in memory and the stimulus does not have to be identical to the prototype, only sufficiently similar for recognition to occur. In this way, variations of the same stimulus can be recognized. Distinctive-features models were developed in an attempt to answer neurological questions of pattern recognition, and have proven to be popular in research regarding letter recognition. The

theory proposes that each stimulus has distinctive features that are stored in memory. These features differentiate one stimulus from another and facilitate discriminability. Research supporting the theory (Gibson, 1969) found that letters that were similar in appearance (P and R) took longer to discriminate between because they had more similar features compared to letters that had completely different distinctive features (C and M). One criticism of the distinct-features model is that although adequate for reasonably simple letter recognition, the theory is inadequate for more complicated tasks such as natural shapes.

Finally, the scene-analysis approach is a very complex model based on computer theories that simulate human perception of visual scenes. A scene-analysis approach developed by Biederman (1987) suggests that pattern recognition involves noting differences in surface characteristics, segmenting a stimulus, and matching component parts to memory representations. Scene-analysis approaches are reasonably new and require further investigation before it can be determined how successful they are.

Much of the research to date regarding recognition, involves words, simple shapes, everyday objects or faces. An adequate review of the available literature is beyond the scope of the present writing, but some of the main findings are as follows: recognition performance is generally superior to recall (Baddeley, 1997), recognition is better for pictorial memory when compared to verbal memory (Paivio, 1976), recognition performance declines as the retention interval increases (Parkin, 1993), and face recognition is enhanced by longer presentation times, shorter retention intervals and

distinctive facial characteristics (Shepherd, Gibling, & Ellis, 1991). Context plays an important role in recognition and studies have found that lines or objects are more readily recognized when presented in a meaningful context (Williams & Weisstein, 1978).

One theory that has had a significant impact on recognition memory research is Signal Detection Theory (SDT). The application of the SDT has defined the performance analysis approach in many psychological studies (Banks, 1970). In essence, signal detection theory “was evolved in an effort to separate the truly sensory aspects of detection from the decision aspects” (Banks, 1970, p.82). It was first developed in the second World War to assess sonar operators (Baddeley, 1997). Egan (1958; cited in Yonelinas, 1994) was one of the first to apply the SDT to memory and over the years it has played a significant role in recognition memory theory. SDT provides two main measures, a measure of discriminability ( $d'$ ) and a measure of the criterion used to make a decision ( $\beta$ ). In relation to recognition,  $d'$  indicates the ability of a participant to accurately discriminate between old and new stimuli while  $\beta$  indicates the level of caution a participant uses when making a judgement. Both  $d'$  and  $\beta$  are theoretically independent of one another; therefore, an increase in  $d'$  should not affect  $\beta$  and alternatively, an increase in  $\beta$  should have no influence on  $d'$  (Macmillan & Creelman, 1991).

SDT is an approach to measuring performance and it has been described as “a way to explain detection experiments, in which weak visual or auditory signals must be distinguished from a “noisy” background” (Macmillan & Creelman, 1991, p. xiii). In addition to the Yes/No response, many recognition experiments ask participants to provide a confidence rating. Confidence ratings are very useful as they provide an indication of familiarity. SDT supports and describes the notion that in addition to recollection processes, recognition judgements are based on an assessment of familiarity (Yonelinas, 1994). Performance on recognition memory is commonly analysed across confidence ratings as recognition is, in most cases, not a clear black and white question. That is, a confidence rating may yield more information than a simple Yes/No response.

Another SDT method used in memory recognition studies is the two-alternative, forced-choice (2AFC) task (Macmillan & Creelman, 1991). Here, a participant may examine a number of stimuli and at some time later be shown pairs of stimuli (either successively or simultaneously). The participant’s task is to indicate which of the stimulus pair was the previously seen target. A 2AFC task eliminates most response bias (Green & Swets, 1966) and a very simple index of recognisability can be used, the percentage of correct recognitions (PC).

One aim of the present study was to investigate possible delayed effects of an ELF MF on recognition memory using a SDT 2AFC task. To date, there are very few studies investigating memory performance and the possible effects of MF exposure. A study

carried out by Cook et al. (1992) investigated MF effects on neurobehavioural measures. One of the seven performance measures included in the study was the digit span memory task which is a well known test used in the Wechsler Adult Intelligence Scale. Series of numbers were verbally presented to participants ranging in length between 4 to 15 numbers. Participants had verbally to recall the numbers in the presented order and then in the reverse order. The number of items successfully recalled forward and backwards was the performance measure. Thirty men participated in weekly test sessions over four weeks under a combination of sham and field exposure conditions. Participants were separated into two groups containing 18 and 12 men each. Group 1 (18 men) were exposed (9 kV/m, 20  $\mu$ T) and sham exposed in two counterbalanced orders. Half of the participants in Group 2 (6 participants) were exposed (9 kV/m, 20  $\mu$ T) in every session while the other half were sham exposed every session. All measures were taken before, during and after exposure. Results supported an earlier screening study in that memory performance measures on the digit span task were unaffected by MF exposure.

A recent epidemiological study by Beale, Pearce, Henning, and Murrell (1997) investigated the theory that adverse psychological effects may be caused by residential exposure to a 50 Hz electromagnetic field. Five hundred and forty participants living near high-voltage transmission lines all completed a range of neuropsychological tests, health ratings scales and other questionnaires. Seven neuropsychological tests were conducted five of which were focused on attentional skills while the other two were focused on memory. The two memory tests included the Selective Reminding Task



which required participants to recall lists of 12 spoken words, and the Visual Memory Task which was extracted from the Wechsler Memory Scale. Participants in the Visual Memory Task had to listen to a sequence of identical blocks tapped out by the experimenter and had to tap out exactly the same sequence in a forward or reverse order. No significant effects of MF exposure were found on memory performance.

The studies above are the only MF experiments known to the researcher that report on measures of memory. In addition, there appear to be no published MF studies that include recognition memory specifically as a performance measure. The inclusion of a memory measure is not, however, unjustified as it has been noted that exposure to environmental toxins often effects memory (Gullion & Eckerman, 1986; cited in Cook et al., 1992). Memory is, after all, a function that humans rely heavily upon and the discovery of even a small MF effect would have significant implications for humans and the environments in which we live. Because it is likely that MF effects on human performance, including recognition memory, are small, studies must be designed with sufficient statistical power to detect these small effects.

### ***Statistical Power***

The main aim of most psychological experiments is to find statistically significant results that support the research hypothesis given that it is true. However, the acceptance or rejection of an experimental hypothesis should not be taken just at face value. Full

consideration should be given to the methods used by investigators to reach conclusions, not least of which is the power of the study to detect any real effect. Statistical power has been defined as the probability of achieving statistically significant results that verify a real effect (Aron & Aron, 1994).

It is not always the case that an effect is detected when the research hypothesis is in fact true. Small to medium effects are often not detected because the power level is too low (Boniface, 1995). When an experimental hypothesis is falsely accepted, a type I error has occurred. Alpha ( $\alpha$ ) is the probability of a type I error occurring and this significance cutoff level is set prior to the study. Most of the research to date regarding MFs has used a conventional alpha level of 0.05.

In contrast, when an experimental hypothesis is falsely rejected, a type II error has occurred. Beta ( $\beta$ ) is the probability of a type II error occurring and statistical power can be considered the probability of not making a type II error (Aron & Aron, 1994; Boniface, 1995). That is, power = 1 - P(Type II error). Typically, in MF research (at least using human participants), P(type II error) is several orders of magnitude greater than P(type I error) (see below).

Over the past 30 or so years, psychological researchers have placed a higher emphasis on preventing type I errors enforcing stringent significance levels that generally require large effect sizes before the null hypothesis can be rejected (Aron & Aron, 1994). However, it is often the case that the probability of a type II error is relatively high. It

has been argued that such an adverse ratio of type I to type II errors is not always appropriate, especially in bioelectromagnetics where the general consensus is that any effects that may exist are small. Therefore, statistical power should be adjusted accordingly. The intention in doing so is not to exaggerate any effects that may be present, but to identify them honestly without falsely accepting the null hypothesis for fear of a type I error. Logic suggests that bias toward either a type I or type II error is questionable in exploratory research; both should be granted equal emphasis (Podd, Page, Rapley, & Beale, 1998).

Effect size (ES) is a major influencing factor on power. Lipsey (1990) defines it as “The magnitude of the real effect to be detected” (p.14). That is, it represents the difference between the standard population and the population which received the experimental manipulation. Less overlap between two populations indicates a greater effect size. One estimate of effect size is obtained by dividing the estimated mean difference between treatment and control groups by the pooled standard deviation (e.g., see J. Cohen, 1988).

The inclusion of ES provides a major advantage when comparing different studies with varying sample sizes and measures. However, researchers alike consider the estimation of ES often to be difficult. One method of determining the expected ES is to base estimation on theory or previous research. Availability of information can be an issue especially if the research field is new. A second method is referred to as minimum meaningful difference, which involves determining the smallest effect that would be

considered important or valuable and calculating the hypothesized mean difference between groups from that.

To achieve a specified power level, an adequate sample size must be used. The larger the number of participants in a study the greater the statistical power. However, obtaining large sample sizes is often costly and impractical. Typically, within EMF research, participation numbers are low. Sample sizes in 19 experiments analyzed in a survey by Whittington and Podd (1996) ranged from 8 to 27. Studies carried out by Whittington et al. (1996) and Kazantzis et al. (in press) are exceptions running sample sizes of 97 and 99 participants respectively. Very rarely do sample sizes exceed 50. The fundamental concepts underlying statistical power analysis are power itself, ES, alpha level and sample size. All four are directly related as any one is a function of the other three. Jacob Cohen was instrumental in demonstrating the importance of statistical power for psychological research in his book "Statistical Power Analysis for the Behavioral Sciences" (1977). Twenty years have since passed and the problem of inadequate statistical power within psychological research is still present. This fact is evident from a number of power surveys that have been carried out beginning with Cohen's extensive 1962 survey. Power levels in psychological studies were generally too low to detect the small-to-medium ESs typically produced by psychological research (Sedlmeier & Gigerenzer, 1989; Rossi, 1990).

In 1996, Whittington and Podd attempted to address the issue of statistical power with the specific focus on human EMF research. Based on the results from 19 experiments, for medium and large ESs, mean power levels of 0.28 and 0.46 respectively were found.

However, the most surprising finding was that for small ESs (probably the norm in MF research) the power to detect such effects was just 0.08. That is, for a small ES (see J. Cohen, 1988) the probability of detecting such an effect was only 8 %, on average. To put this finding more dramatically, for small ESs, a typical EMF study had a 92% chance of failing to detect the effect, or failing to replicate a previous result.

Relaxing the alpha level is the easiest way to increase power. In the context of EMF research it has been suggested that the conventional alpha level of .05 is inappropriate (J. Cohen, 1977; Whittington & Podd, 1996). With the combined knowledge that any MF ES is going to be relatively small and that the EMF research field is still very much in an explorative phase, the risk of a type II error is just as important, if not more so, than the risk of a type I error. A minimum power level of .80 was suggested by Cohen (1977) which would provide an 80% chance of detecting an existing effect. As Whittington and Podd (1996) showed, the reality in MF research is that for small ESs statistical power is only about one tenth of Cohen's recommendation.

Cohen (1962) alluded to the fact that many worthwhile investigations providing valuable information have been dismissed, producing nonsignificant results primarily because of low power. Since Cohen's early revelations regarding power, little has been done to rectify the problem. Aron and Aron (1994) state that "this stubborn failure by researchers to consider power is a bit shocking. It means that more often than not researchers are going through all of their work for nothing" (p. 233). In keeping with

current research practices in the MF laboratory at Massey University, the present study paid particular attention to statistical power levels.

### *Purpose of the Present Study*

The main purposes of the present research were to replicate in part the Whittington et al. (1996) study and to investigate any possible delayed effects of MF exposure on recognition memory. Whittington et al. showed that when exposed to a 50 Hz, 100  $\mu$ T magnetic field, RT on a relatively difficult visual duration discrimination task increased significantly. In the present study, the same two alternative, forced choice visual duration discrimination task was used, but with only a hard level of difficulty. The purpose of using only the most difficult level of the task because Whittington et al. reported a MF effect only at this level. The hypothesis was that the inclusion of an increased number of only hard trials would increase the likelihood of detecting any effect (increased experimental sensitivity).

To date, there has been a great shortage of studies investigating MF effects on humans. It is hardly surprising, then, that very little research has investigated possible MF effects on memory and no published studies have specifically measured recognition memory. The present study had the additional aim of extending existing research, regarding MF effects on human performance, by examining recognition memory performance in relation to a possible delayed MF effect. A 2AFC recognition memory task presenting

abstract shapes was used to measure recognition memory performance. The visual duration discrimination task was placed within the retention interval of the recognition memory task. Participants first observed a series of abstract shapes that they would have to recognize at a later time. Then half of the participants were MF exposed during the visual duration discrimination task while the other half were sham exposed. Finally, all participants completed the test phase of the recognition memory task, half having been MF exposed during the visual duration discrimination task. In this way, the experimental design allowed for the investigation of the concurrent effects of a MF on visual duration discrimination and the delayed effects of the same field on recognition memory.

## METHOD

### *Participants*

Eighty participants completed the study, 30 males and 50 females. The majority were undergraduates and postgraduates in the School of Psychology at Massey University aged between 19 and 53 years. Before the experiment began, participants were required to fill in a pre-screening questionnaire asking if they: 1) had previously participated in magnetic field research; 2) were pregnant; 3) had any chronic health problems; 4) had any cardiovascular problems; 5) had a history of brain or nervous system damage or disorder; 6) had had an illness which confined them to bed for more than 3 days in the previous 3 months; 7) were currently undergoing psychotherapy or were contemplating such treatment; 8) were taking any medication; 9) had any dietary restrictions or unusual dietary habits; or if 10) wore any form of metal prosthesis, or had any implanted metal or electronic devices. The screening questionnaire criteria (Appendix A) were adapted from Cook et al. (1992). A 'yes' answer to any of the above questions meant that a participant was debriefed immediately, taking no further part in the study.

In addition to the screening questionnaire, participants were provided with an information sheet to read and consent form to sign before the study began (see Appendix A). The information sheet provided participants with a brief introduction to ELF magnetic fields, the purpose of the study, details on procedures for the three parts of the study, and the possible risks and benefits of the study. Participants were informed



of their right to withdraw and to ask questions at any time during the study. All information was presented to participants except where the double-blind procedure would have been jeopardized. An extensive proposal was submitted to the Massey University Human Ethics Committee outlining and describing the purpose and procedures of the study. Full approval was obtained.

### *Experimental Design*

The study was designed in such a way that it allowed for the immediate effects of an intermittent ELF MF on visual duration discrimination to be investigated. In addition, the delayed effects of this intermittent MF on recognition memory for abstract shapes were also investigated. Participants were first shown 40 abstract shapes individually presented in the study phase of the recognition memory task. They then completed 25 practice trials and 200 experimental trials of a visual duration discrimination task.

Finally, participants completed the test phase of the recognition memory study. In this way, it was possible to study both the immediate and delayed effects of the MF on both a visual duration discrimination task and a recognition memory task respectively.

Investigating the effects of the MF on these two tasks in the same study necessitated the use of a between-groups design, where half of the participants were exposed to an ELF MF while the other half of participants were sham exposed.

Time-of-day effects were controlled by randomly assigning participants to either the morning or afternoon session. Time of day and exposure conditions were counterbalanced under double blind procedures. Half of the sham exposed participants (N = 20) completed the experiment in the morning while the other half (N = 20) completed the experiment in the afternoon. Likewise, 20 participants were field exposed in the morning and a further 20 participants were field exposed in the afternoon (see Figure 2).

	Morning (0900 - 1200 hrs)	Afternoon (1400 - 1700 hrs)
Sham Exposure	N = 20	N = 20
Real Exposure	N = 20	N = 20

*Figure 2.* Number of participants in the sham and real exposure conditions during experimental sessions run in the morning and afternoon.

Morning sessions were held between 900 and 1200 hours while afternoon sessions were held between 1400 hrs and 1700 hrs. Participants were led to believe that everyone in

the study would be exposed to the magnetic field during the visual duration discrimination trials. The experimenter was blind as to which condition was being run with the computer controlling whether participants in any given session were sham or real exposed on a random basis.

### *Measures*

Three performance measures and two subjective measures were used as dependent variables. Percentage of correct decisions (PC) and reaction time (RT) were recorded for experimental visual duration discrimination trials. Two hundred 2AFC visual duration discrimination trials were completed under either real or sham exposure conditions. Participants were asked to compare two flashes from a light emitting diode (LED) and indicate which of the two was longer in duration. Every trial contained one LED flash of 50 ms and another LED flash of 65 ms with the order of presentation randomized. The 15 ms difference between the standard and comparison flashes presented participants with a relatively difficult discrimination task. The choice of this difficulty level was based on the results obtained by Whittington et al. (1996). They found a MF performance effect (speeded RT) on visual duration discrimination, but only when the discrimination task was relatively difficult. Whittington et al. found a mean PC value of 62% for the same task and level of difficulty used in the present study.

For the recognition memory task, PC and confidence ratings were obtained for 40 recognition trials also using a 2AFC procedure. Participants viewed 40 shapes followed by a period of approximately 15 minutes during which they completed the visual duration discrimination task. Then the recognition phase was completed in which participants were presented with 40 pairs of shapes. Participants had to choose which of the two shapes they had seen previously. For each of the 40 pairs of shapes, they also had to give a confidence rating on a four point rating scale (1 = very sure, 2 = sure, 3 = not so sure, 4 = unsure). Participants recorded all responses on an answer sheet (see Appendix B) which was later scored manually with an answer template.

Participants and the experimenter completed a Field Status Questionnaire (FSQ) at the end of each experimental session. The questionnaire was developed by Cook et al. (1992) and was designed to assess the adequacy of double-blind procedures. Respondents had to indicate whether they thought the MF field was on or off during visual duration discrimination experimental trials (see Appendix B for a copy of FSQ).

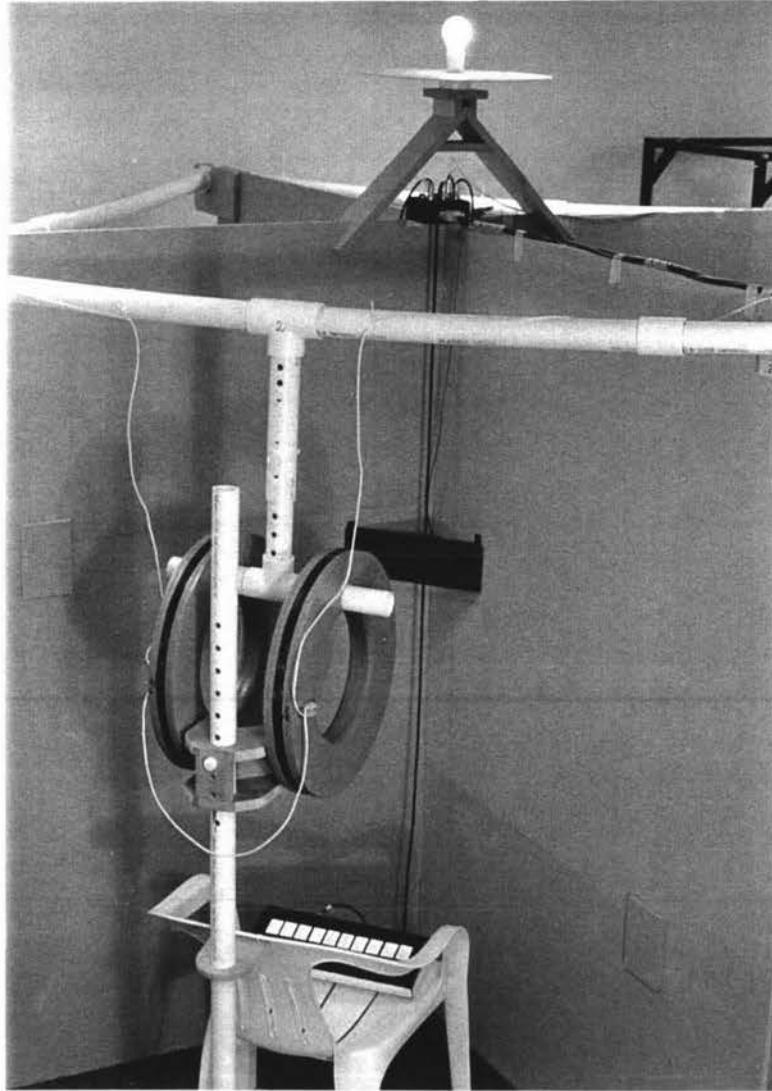
### *Apparatus*

The entire experiment was carried out in an unshielded room measuring 5.5 m x 4.5 m. Lighting was provided by a 60 watt back light located in the center of the exposure apparatus. During the recognition memory task participants were seated adjacently at a long table measuring 2.42 m in length. A Sony Triniton 21" flat screen RGB monitor

(model No. GVM-2110QM) with SVGA resolution was centrally located in front of the participants at a distance of 1.05 m. Connected to the screen was a 486 DX4 IBM computer. The Experimental RunTime System (ERTS) software package was used to develop the recognition memory task. Beringer (1995) describes ERTS as “a software package for developing and running non-adaptive, trial-oriented reaction time experiments and continuous tracking tasks” (p.1). A keyboard connected to the IBM computer was used for manual control over the visually presented instructions. Computerized instructions were only used for the recognition memory task in both the study and test phases (see Appendix C). Pre-recorded, standardized audio instructions were played on a TCM 5000 SONY cassette recorder. Audio instructions were used at the very beginning of the recognition memory study phase and during the visual duration discrimination task (see Appendix C).

The visual duration discrimination task was completed in a four-cubicle apparatus constructed completely from non-metal materials used for ELF MF exposure. Each cubicle was identical, containing a plastic chair, a response pad, a headrest, a pair of Helmholtz-configured coils and a LED board (see Figure 3). Chairs were precisely positioned at the outer edge of the apparatus facing inward. An adjustable wooden headrest located at the back of the chair provided comfort and stabilized the head. Light flashes for the visual discrimination tasks were emitted from a LED housed in the center of a small black board. The LED was located 0.79m from the headrest and adjustable to eye level along velcro strips. Helmholtz-configured coil sets produced homogeneous MFs and participants' heads were carefully positioned between each pair of coils. The

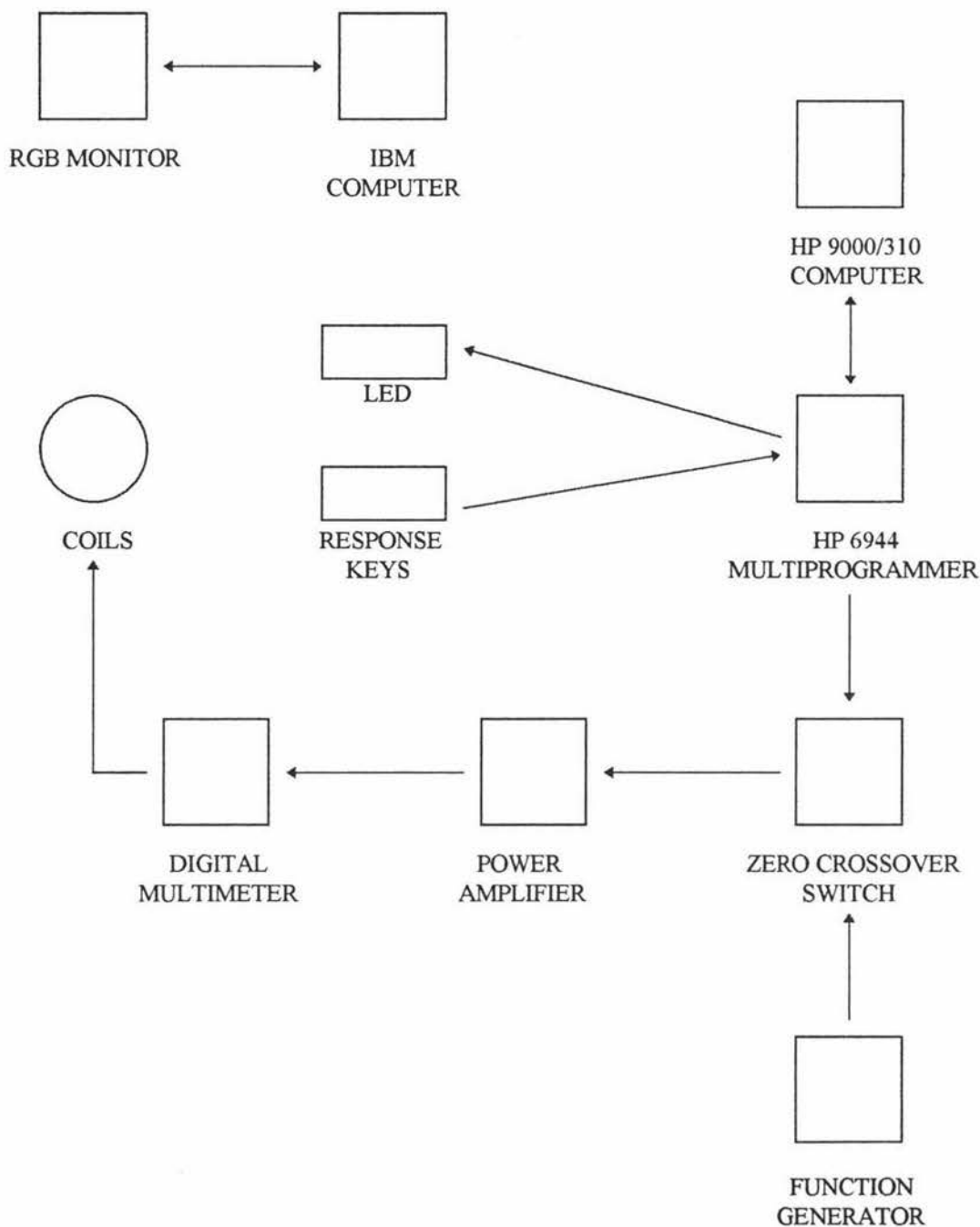
coils were adjustable in height and the intercoil distance was set at 0.2m (equal to the coil radius) to ensure true Helmholtz configuration was maintained. The width between coils was



*Figure 3.* Exposure apparatus showing four cubicles positioned at right angles, each one containing an adjustable pair of coils, a LED board (the black board located at inner corner), a plastic chair, a headrest, and a response pad (resting on chair).

adjustable when positioning participants' heads and each pair was returned to the set distance of 0.2 m before the trials began. Each coil was made up of 120 turns of .0015 m resin-coated copper wire with a radius of 0.2m. The four pairs of coils, connected in series, were positioned at right angles to one another and the center of the left-hand coil in one set was 1.13 m from the center of the right-hand coil on the adjacent coil set. During sham exposure, participants sat in the exposure facility but no current flowed through the coils. During field exposure, a 50 Hz, intermittent (1s on, 1s off), sinusoidal MF with a field strength 100  $\mu$ T was produced by the current passing through the coils. The parameters of exposure were checked with a F.W. Bell (model 9200) gaussmeter, using a Hall effect probe. A calibrated coil with 100 turns of .0004m enameled copper wire connected to a voltmeter (adapted to function as a gaussmeter) was used each day to check for the presence of a MF at each set of coils.

Figure 4 shows a flow diagram of the experimental apparatus. A Hewlard Packard (HP) 9000/310 computer and a HP 6944 multiprogrammer controlled the visual duration discrimination task, in regard to stimulus presentation, timing and data acquisition. For each experimental session, the computer randomly determined whether the MF would be on or off. Neither the experimenter nor the participants knew which condition was being run. The field strength was monitored by the computer and a shut down system was programmed to cut the current off if at any time it exceeded or fell below set parameters. A 50 Hz sine wave was produced by a function generator and then passed through a zero crossover switch. The zero crossover switch turned the current off and on (one s off, one s on) to create an intermittent MF during real exposure sessions, and



*Figure 4.* Flow diagram of the ELF magnetic field exposure system. The RGB monitor and IBM computer were independent of the main system, being used for the recognition memory task only (see text for further details).



was turned off during sham exposure sessions. A current of .18 A (rms) was produced by a transconductance amplifier which then sent the signal to the coil pairs via a Fluke 75 digital meter that monitored the sine wave output. With the current switched on, the coils produced no sound, vibration, or thermal radiation, even after several hours of continuous operation.

### *Tasks and Sequence of events*

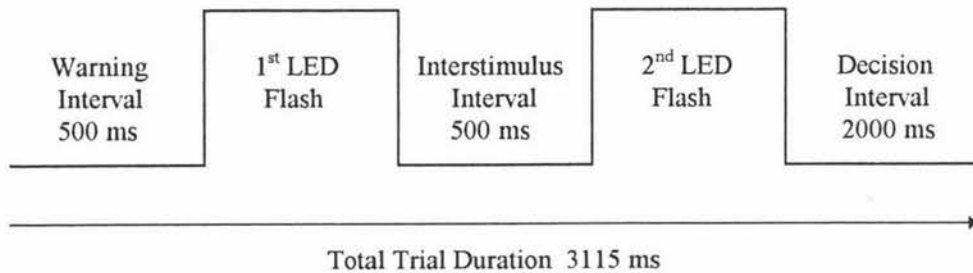
The recognition memory task was carried out in two phases (study phase and recognition phase) with a 14-15 minute interval separating them, during which the visual duration discrimination task was conducted. During the study phase, 40 abstract shapes (see Appendix D for an example) were sequentially presented in a random order. Each shape was presented in the center of the screen for 3 s followed by an interstimulus period of 0.5 s during which the screen was blank. The screen had a background colour of blue and each shape was encased in a box with a white background. The object of the study phase was for participants to commit the shapes to memory.

Before the recognition phase began, participants completed the visual duration discrimination task, taking 14 to 15 minutes. The recognition phase began with six practice trials aimed at familiarizing participants with the sequencing of events, timing and response procedure. On each practice trial, two three-digit numbers were presented side by side on the screen for 6 s. Each pair consisted of one three-digit number

containing the same number repeated (e.g., 111, 777, 444), while the other three-digit number contained three different numbers (e.g., 234, 537, 169). During the 6 s presentation period, participants had to pretend that they had seen one of the numbers previously and accordingly judge which of the two numbers they had seen before. All responses were made on an answer sheet and participants also had to rate their confidence in each judgement. The "L" option was circled if they recognized the number on the left side or "R" option was circled if they recognized the number on the right side as previously seen. Confidence levels were indicated on a 4-point rating scale by circling 1 for "very sure", 2 for "sure", 3 for "not so sure", or 4 for "unsure". A small number in the top left corner of the screen corresponded with the trial number on the answer sheet and an interstimulus interval of 1.0 s (screen blank) followed each presentation interval. Practice trials were repeated if a participant failed to use the correct response procedure on more than one trial.

Forty experimental trials were completed in which two abstract shapes were presented side-by-side on the screen. One of the shapes was a target stimulus which participants had seen previously during phase one, and the other shape was a distractor stimulus. Targets and distractors differed in a number of possible ways, including additional lines, part colour changes, and so on. The task was to judge which shape had been viewed during the study phase. Sequencing of events, timing of stimulus presentations and response procedures were identical to those present during the practice trials.

The visual duration discrimination task involved 25 practice trials and 200 experimental trials. Participants had to meet set performance levels on practice trials before commencement of experimental trials. If any one participant did not produce a PC value of at least 50% or failed to respond on more than three trials, a new set of 25 practice trials were completed by all participants in that experimental session. Each visual discrimination trial had a set sequence of events as outlined in Figure 5.



*Figure 5.* Temporal sequence of events for one visual duration discrimination trial.

Initially, a 1000 Hz, 100 ms long warning tone emitted by the computer signaled the beginning of the trial. A 400 ms waiting period followed after which the visual discrimination stimuli for the task were presented. Two consecutive flashes of light were emitted from the LED separated by a 500 ms interstimulus interval. One LED flash was 50 ms in duration while the other LED flash was 65 ms in duration with the

order of presentation randomized. After the second LED flash, a 2000 ms decision interval provided participants time to decide which of the two flashes was longer in duration. Responses were made on a response pad that rested on the knees. Button 2 was pressed with the left hand forefinger if the first LED flash was longer and button two was pressed with the right hand forefinger if the second LED flash was longer. Responses made after the 2000 ms decision interval had ended were not recorded and less than 1% of trials were lost. The total time for each trial was 3115 ms and an approximate 30 s rest period occurred after the first 100 experimental trials.

### *Procedure*

The study involved two tasks, the nonverbal recognition memory task and the visual discrimination task. A maximum of four participants could partake in any one experimental session and all participants completed both tasks. Initially, participants were shown the experimental facilities and were seated adjacently at a long table. Each seating position had an allocated number (from one to four) and participants were positioned facing the 21" RGB VDU. Participants read an information sheet and completed a screening questionnaire and consent form. The study phase for the recognition memory task began and standardized, pre-recorded instructions were played on a cassette player (see Appendix C for copy of instructions). The instructions informed participants that 40 abstract shapes would be sequentially presented on the

screen before them. They were asked to concentrate and try to commit the shapes to memory as they would later be asked to remember what shapes they had viewed.

Further instructions (see Appendix C) were then presented on the VDU for participants to read. Presentation of instructions were manually controlled by the researcher to accommodate the different reading speeds of participants. Forty abstract colour shapes were sequentially presented in a random order and each shape was displayed for three seconds before being replaced by a new shape.

Following the completion of the study phase, participants were moved to the numbered cubicle corresponding to their seating number during the study phase. Each participant sat on a plastic chair facing inwards toward the center of the exposure apparatus. Two Helmholtz-configured coils were positioned either side of participant's heads, resting just above the shoulders. Standardized, pre-recorded instructions were played (see Appendix C for instructions) and all participants were told that they would be exposed to an ELF MF during the experimental trials. During each trial participants watched two consecutive light flashes emitted from a LED directly in front of them. The task was to indicate which of the two light flashes was longer in duration. Responses were made by pressing one of two buttons on a response pad resting on the knees. Participants were asked to respond as quickly as possible while maintaining accuracy.

Twenty-five practice trials were initially run and performance data were presented on the HP computer. All participants in the experimental session repeated the practice trials if

any participant failed to respond on more than three trials, or produced less than 50% performance accuracy. No MF was generated during the practice trials.

Participants then completed a total of 200 visual duration discrimination experimental trials. An approximate 30 s break after the first 100 trials allowed participants to rest their eyes while remaining seated in the exposure facility. Only half of participants ( $N = 40$ ) were exposed to an ELF MF during experimental visual duration discrimination trials while the other half of participants ( $N = 40$ ) were sham exposed. Following the 200 visual duration discrimination task, participants returned to their numbered seating position at the long table. The recognition phase of the memory task began and all instructions were presented on the VDU (Appendix C). Again, the experimenter used a keyboard to manually control instruction presentation rate. Participants were told that during the recognition phase, they would be presented with pairs of abstract shapes and their task was to recognize which shape they had seen during the study phase. Initially, participants completed six practice trials to familiarize themselves with the response procedure and timing of events. Each practice trial presented two three-digit numbers side by side on the screen for six seconds (e.g., 777, 456; 222, 571). Participants responded on a practice sheet indicating which of the two numbers they had “hypothetically” seen before. If they recognized the shape displayed on the left side they circled “L” and if they recognized the shape on the right side they circled “R”. They also rated their confidence in each judgement on the four point rating scale. A small number displayed in the top left corner of the screen corresponded to the trial number on

the answer sheet. If any participant failed to use the correct response procedures in more than one practice trial, the practice trials were repeated.

Following the recognition practice trials, participants completed 40 experimental trials with the abstract shapes. Participants were asked to respond on every trial, guessing when unsure. The sequencing of events and response procedures were identical to those used in the practice trials.

The completion of the 40 experimental trials marked the conclusion of the recognition memory task. Participants were fully debriefed and informed of the mild deception used in the study. Participants were told that during the visual duration discrimination experimental trials, the MF could have been on or off. Double-blind procedures were fully explained and participants filled out a FSQ indicating whether they thought the field was on or off during phase two. A brief discussion between participants and the researcher provided an opportunity for any questions to be asked. Participants were offered a copy of their personal data and the study findings, if they so desired.

### ***Data Analysis***

Normally, a multivariate analysis of variance (MANOVA) would be used to analyse the major performance effects of the within-groups and between-groups factors when there are two or more dependent variables such as in the present study (Tabachnick & Fidell,

1989). However, in the present study PC and RT were not significantly correlated (see results) and the decision was made to analyse each variable independently using univariate analyses of variance (ANOVA). Separate ANOVAs for PC and RT were calculated with the Statistical Package for the Social Sciences for Windows (SPSS, SPSS Inc., 1997). The sphericity assumption was met for both PC and RT (using Box's M) and homogeneity of variances was established (see results for further details).

Significant effects reported in the present study include the exact  $p$  value and the observed ES (J. Cohen's  $f$ , calculated from partial  $\eta^2$ ; see J. Cohen, 1988). For univariate tests, partial  $\eta^2$  was calculated using the equation:  $\eta^2 = [F \times (\text{df effect})] / [F \times (\text{df effect}) + \text{df error}]$ . Partial  $\eta^2$  was then used to calculate Cohen's ES for an  $F$ -test using the equation:  $f = [\eta^2 / (1 - \eta^2)^{1/4}]$  (Cohen, 1977).

To increase statistical power (SP) the alpha level for the present study was relaxed to 0.30 for all main and interaction effects of Exposure Condition while the remaining effects maintained the conventional alpha level of 0.05. A comparatively large number of participants ( $N = 80$ ) also aided in increasing SP. All SP calculations were conducted post hoc with GPOWER, a program for calculating power (Erdfelder, Faul, & Buchner, 1996).



## RESULTS

### *Analysis of the FSQ*

The FSQ provided valid data for all 80 participants. The experimenter completed the FSQ for each experimental session and the combined data supported the efficacy of the double-blind procedure. When deciding whether the field was on or off, 50 % (chance level) of responses were expected to be correct. The experimenter and participants accurately determined when the field was on or off 50% and 55% of the time, respectively. Neither result was significantly different from the expected value of 50 %. However, results indicated that participants were significantly biased toward selecting the “field on” judgement with 58 participants judging the field to be on and only 22 judging it to be off. A chi square analysis confirmed that this effect was significant,  $\chi^2(3, N = 80) = 17.00, p = 0.0007$ .

### *Analysis of Visual Duration Discrimination Task*

#### *Performance Measures: Accuracy and Reaction Time*

Tests analyzing the effect of the MF used a family-wise alpha level of 0.30 while all other tests used the conventional 0.05 alpha level. Equal variances were assumed for

both PC and RT after an Independent Samples Test found no MF effect for either variables. Individual MANOVAs for both PC and RT were carried out. The Box's Test of Equality of Covariance Matrices was conducted for each variable to test the null hypothesis that the observed covariance matrices of the dependent variables were equal across groups. For PC, the test was non-significant, Box's  $M(3, 1095120) = 3.86, p = 0.29$ . Thus, the sphericity assumption was met indicating homogeneity of variances; therefore, univariate tests were used for further analyses. For RT, the sphericity assumption was also met, Box's  $M(3, 421556) = 6.82, p = 0.09$ , and univariate tests for this dependent variable were conducted as well.

A small negative Pearson's  $r$  (-0.15) was found between PC and RT showing that as PC increased RT slowed slightly. However, this result did not reach significance, and PC and RT were analysed independently. The 200 experimental trials were separated into two blocks of 100 trials each to investigate whether Block had any effect on the dependent variables. In addition, the Block by MF field interaction was investigated. Block 1 represented the first set of 100 trials and Block 2 represented the second set of 100 trials.

### *Accuracy*

On average, participants showed a small decline in PC when exposed to the MF ( $M = 58.10\%$ ,  $SD = 6.00$ ) compared to sham exposure ( $M = 59.10\%$ ,  $SD = 5.00$ ) (see Table

3). However, the 1% decline in mean PC performance under MF exposure was not significant ( $F < 1$ ).

**Table 3**

Mean percent of correct decisions and reaction time for participants in sham or real exposure conditions. SDs are shown in parentheses.

EXPOSURE CONDITION	PERFORMANCE MEASURE
	PC (visual duration discrimination) <sup>a</sup>
Sham	59.10 (5.00)
Real	58.10 (6.00)
	Reaction Time (nearest ms)
Sham	760 (150)
Real	760 (160)

*Note.* PC and SD values were originally calculated as a proportion to two decimal places. The present study presented PC as a percentage and thus SDs were rounded off to a whole number. <sup>a</sup>The values represent percentages of correct discriminations.

Multivariate tests were run to see whether there was any interaction between MF exposure and Block 1 (first set of 100 visual duration discrimination trials) or Block 2 (second set of 100 visual duration discrimination trials) PC values. The results indicated no Block by MF exposure interaction ( $F < 1$ ). However, an overall Block effect

(regardless of exposure condition) on PC was observed with a 1.80% improvement in PC in Block 2. The overall mean PC values for Blocks 1 and 2 were 57.70% ( $SD = 6.00$ ) and 59.50% ( $SD = 7.00$ ) respectively (see Table 4). With an alpha level of 0.05, there was a significant interaction between Block and PC,  $F(1, 78) = 3.99, p = 0.05, ES = 0.24, SP = 0.56$ .

**Table 4**

Mean percent of correct decisions and reaction time for all participants during Blocks 1 and 2 of the visual duration discrimination task. SDs are shown in parentheses.

BLOCK	PERFORMANCE MEASURE
	PC (visual duration discrimination) <sup>a</sup>
BLOCK 1	57.70 (6.00)
BLOCK 2	59.50 (7.00)
	Reaction Time (ms)
BLOCK 1	780 (180)
BLOCK 2	730 (160)

*Note.* PC and SD values were originally calculated as a proportion to two decimal places. The present study presented PC as a percentage and thus SDs were rounded off to a whole number. <sup>a</sup>The values represent percentages of correct discrimination.

### *Reaction Time*

Data from only 49 participants provided RT results as a system failure rendered the results from the remaining 31 participants unusable. Of the 49 participants, 24 were sham exposed and 25 were MF exposed. The mean RT values were calculated from the median RT values calculated for each participant from the raw data. No evidence for a MF effect on RT was found with both sham and exposure conditions providing mean RTs of 760 ms (see Table 3). Not surprisingly, then, there was no main effect of MF exposure on RT ( $F < 1$ ).

There was no significant Block by MF exposure interaction for RT. However, as for PC, an overall Block effect was observed for RT. On average, participants showed significantly faster RTs for Block 2 ( $M = 730$  ms,  $SD = 160$ ) compared to Block 1 ( $M = 780$  ms,  $SD = 180$ ) (see Table 4). With an alpha level of 0.05, there was a significant interaction between Block and RT,  $F(1, 78) = 9.59$ ,  $p = 0.003$ ,  $ES = 0.35$ ,  $SP = 0.87$ .

In summary, no significant effects were found for MF exposure for PC or for RT. An overall Block effect was found with significant improvements in performance on both PC and RT during the second block of 100 visual duration discrimination trials. However, disappointingly, there were no MF main effects and no Block by MF interaction effects for either PC or RT.

## *Analysis of Recognition Memory Task*

### *Accuracy*

Data for all 80 participants were used for the recognition memory task analyses. Results indicated that recognition accuracy was affected after participants had been exposed to the MF. The mean recognition PC values for sham and exposure conditions were 75.20% ( $SD = 9.80$ ) and 69.80% ( $SD = 11.60$ ), respectively, producing a mean difference of 5.40% (see Table 5). The decline in recognition PC after being exposed to a MF was significant,  $F(1, 78) = 5.14$ ,  $p = 0.03$ ,  $ES = 0.26$ ,  $SP = 0.90$ .

### *Confidence*

A delayed effect of MF exposure on confidence ratings was also observed in the memory task. It will be recalled that participants were asked to rate their confidence in the response made on each trial. Participants were required to indicate their confidence on a four point rating scale (1 = very sure, 2 = sure, 3 = not so sure, 4 = unsure). Mean confidence ratings for participants who had been previously sham or MF exposed were 2.33 ( $SD = 0.35$ ) and 2.47 ( $SD = 0.27$ ) respectively (see Table 5). As the confidence rating scale ranged from 1 (very sure) to 4 (unsure), the increase in mean confidence after exposure indicated a decline in actual confidence. The effect of prior MF exposure on confidence was significant,  $F(1, 78) = 4.21$ ,  $p = 0.04$ ,  $ES = 0.23$ ,  $SP = 0.53$ .

**Table 5**

Mean percent of correct decisions and confidence ratings on the recognition memory task for participants who had been either sham or MF exposed. SDs are shown in parentheses.

EXPOSURE CONDITION	MEASURES
	PC (memory) <sup>a</sup>
Sham	75.20 (9.80)
Real	69.80 (11.60)
	Confidence
Sham	2.33 (0.35)
Real	2.47 (0.27)

<sup>a</sup>The values represent percentages of correct responses for the recognition memory task.

### *Accuracy and Confidence*

A moderate correlation (Pearson's  $r = 0.35$ ) was found for confidence and accuracy. As PC increased so too did confidence. Further analysis investigated whether the correlation of accuracy and confidence differed between participants who were previously sham exposed and participants who were previously exposed to a MF. A Pearson's  $r$  correlation of 0.37 was observed for confidence and accuracy in the sham

exposure condition and a Pearson's  $r$  correlation of 0.25 was observed for confidence and accuracy in the field exposure condition. To test whether the difference between these two correlations of 0.12 was significant, Fisher's  $Z$  transformation was used (Kleinbaum & Kupper, 1978). For the two-tailed test with an alpha level of 0.30, a critical value of 1.04 or more was required to reach significance. A Fisher's  $Z$  value of 0.57 was found and thus, no significant difference was observed between the confidence accuracy correlations for participants who had been previously sham exposed and those who had been previously field exposed. The results therefore suggest that there is no delayed MF effect on the correlation between accuracy and confidence.

To summarize, participants who had been previously exposed to a 50 Hz, 100  $\mu$ T MF during the visual duration discrimination task were less accurate and less confident on the recognition memory task when compared to participants who had been previously sham exposed. In addition, while there was a small difference in correlation between accuracy and confidence in the real and sham conditions, this difference did not reach significance.



## DISCUSSION

The results from the present study failed to support the hypothesis that MF exposure would slow RT on a visual duration discrimination task. When compared to sham exposure, participants' average RT values were not significantly effected when exposed to a 50 Hz, 100  $\mu$ T intermittent magnetic field. However, a delayed MF effect on human performance was observed during the recognition memory task. Participants who had been previously field exposed produced an accuracy value, on average, 5.40% lower than participants who had been previously sham exposed. In addition, recognition memory confidence ratings dropped significantly when participants had been previously field exposed.

### *FSQ Analysis*

In the present study, participants were unable to identify which condition they were exposed to at better than chance level but a bias toward reporting they had been exposed to a MF was observed. Kazantzis et al. (in press) found similar results of MF exposure bias and explained the reaction as possible misattribution of increased arousal to magnetic field exposure. That is, participants are anxious initially and attribute this anxiety to the presence of a MF. As participants become more familiar and comfortable

with the experiment, arousal subsides giving the impression that the MF has been turned off.

The above explanation is speculative, but Kazantzis et al. (in press) suggest a study to test the explanation. Participants could complete the same task over more than one experimental session and measures of anxiety could be gathered at the beginning and end of each session. If participants completed, say, five sessions, it would be expected that anxiety levels would be the highest for the first session and would reduce over consecutive experimental sessions. As sessions progressed, participants would become more familiar with the task and would thus, be less likely to display the “field on” judgement bias.

### *Visual Duration Discrimination*

The visual duration discrimination task in the present study involved 200 trials separated into two blocks of 100 trials. Participants produced significantly better performances in both PC and RT during the second block of trials, probably due to a practice effect.

There was no Block by MF interaction for either measure ruling out the possibility that the MF produced the improved performance level. Furthermore, there was no MF main effects, suggesting that neither PC nor RT were affected by the applied MF. Evidence from previous research has indicated that ELF MFs can effect human performance (e.g., Cook et al., 1992; Graham & H. D. Cohen, 1985; Graham et al., 1994; Whittington et al., 1996). However, the research to date still remains inconclusive due to the varying

experimental parameters used, low statistical power and lack of replication. The aim of the present study was to address some of these issues by replicating in part the Whittington et al. (1996) study, maintaining similar experimental parameters and a reasonably high level of statistical power.

Whittington et al. (1996) exposed participants to both sham and MF conditions during a visual duration discrimination task that contained three levels of difficulty (hard, intermediate and easy). It was found that for the field exposed/hard task condition, participants produced RTs that were, on average, 14ms slower than participants who were sham exposed. RT values were not affected by the MF for the intermediate and easy levels, and PC was unaffected by the MF at all levels of difficulty. The present study supported the Whittington et al. study in that a null result was found for PC during the visual duration discrimination task. However, a null result was also observed for RT under MF exposure conditions during the visual duration discrimination task and the hypothesized slowing of RT was not observed.

There are a number of reasons that could account for the null RT results obtained in the present study for the visual duration discrimination task. Although the present study aimed at replicating, as close as possible, the Whittington et al. (1996) study by using exactly the same laboratory and visual duration discrimination task, changes were made in an attempt to maximize sensitivity while minimizing any effect of extraneous variables. The present study used only the hard level of task difficulty because Whittington et al. found a MF exposure effect on RT only at the hard level of the visual

duration discrimination task. In the current study, it was thought that by running only the most difficult level of the visual duration discrimination task, the chances of observing a MF effect would be maximized. In hindsight, this adjustment may have affected the outcome of the present study as the Whittington et al. study included trials that were randomized across three levels of difficulty compared to just one level in the present study.

Participants in the Whittington et al. (1996) study completed 150 visual duration discrimination trials of which about 50 were at each of three difficulty levels. In comparison, participants in the present study completed 200 trials (two blocks of 100 trials separated by a 30-second break) all at the hard level of difficulty. The number of trials was increased to raise the reliability of results and the inclusion of only hard trials was to increase sensitivity to MF effects. The large number of difficult trials used in the present study and the absence of easier task trials may have affected performance. When compared to Whittington et al. (1996) accuracy for hard trials decreased by 3.41%, despite the task and difficulty level being identical in the two studies. Participants in the present study consistently reported that they could not perceive any difference between the flashing lights. The absence of interspersed easier trials may have produced a task that was perceived as very difficult with participants never gaining relief or encouragement from experiencing some easier trials. In order to fairly replicate Whittington et al. (1996), an exact replication study including all three levels of task difficulty is required. Until such research is carried out, the null results of the present investigation must be viewed with caution.

### *Recognition Memory*

In contrast to the null results gained in the visual duration discrimination task, exposure to a 50 Hz MF did have a significant delayed effect on recognition memory. A significant reduction in PC for recognition memory was observed for participants who had been previously field exposed when compared to participants who had been previously sham exposed. Similarly, there was a significant drop in confidence for participants who had experienced prior field exposure.

Although no known published research has investigated the possible delayed effects of an ELF MF on recognition memory performance, previous studies have reported performance decrements immediately following exposure. Graham and H. D. Cohen (1985) tested participants on a signal detection task during sham and real exposure conditions. Performance was better during real exposure, and worse immediately after real exposure. Graham et al. (1994) also found performance decrements immediately after field exposure when participants had been tested on an auditory signal detection task and a DRL task. However, these studies tested the same task during and after exposure in both sham and real exposure conditions while the present study tested performance on a visual duration discrimination task during exposure and recognition memory after exposure.

The delayed effect of the MF on recognition memory accuracy was 5.4% (ES = 0.26), suggesting a relatively strong effect of the MF. In addition, confidence increased as recognition memory PC increased and, like recognition memory PC, dropped significantly when participants had been previously field exposed. It is extremely important that this study be replicated because the findings indicate that recognition memory may be a good measure of delayed weak ELF magnetic field effects. However, even if the effect can be replicated, there are at present no completely plausible mechanisms that might be used to explain how weak MFs affect memory, or biological systems in general. Researchers have attempted, unsuccessfully, to address this issue resulting in the development of many theories presenting possible mechanisms of interaction through which MFs affect biological systems. One of the most favoured theories is that changes occur at a cellular level in the brain and central nervous system (Cook et al., 1992; Lednev, 1991; Polk, 1991; Sagan, 1996). Additional theories such as induced currents, transients, effects of magnetite, and resonance all provide possibilities but none are sufficiently developed to predict the results obtained in this current study. Little research has been carried out on confidence ratings but some studies on eyewitness testimony have suggested an affect opposite to that observed in the present study (Baddeley, 1997). That is, confidence can be very high when accuracy is low. However, no firm conclusions can be drawn and it is hard to know why recognition memory confidence is different outside of the field because there is simply no research (apart from the present study) that has investigated this effect. Nonetheless, the present results on recognition memory are exciting, especially if they stand up to replication.

### *Statistical Power*

The majority of research investigating MF effects on humans has contained insufficient statistical power (Whittington & Podd, 1996). It is likely that any effects that do exist are very small and thus statistical power must be reasonably high in order for these effects to be detected. However, many researchers still refuse to address this issue and continue to run experiments that have virtually no chance of detecting any real, albeit small, effects. The present study was designed in an attempt to increase statistical power and thus raise the level of sensitivity. All visual duration discrimination trials were at a hard level of difficulty because previous research had shown only the hard task difficulty to be sensitive to MF effects (Whittington et al, 1996; Kazantzis, et al., in press). In addition, sample size was relatively large and the conventional alpha level was relaxed to further increase statistical power and minimize the risk of making a type II error.

Sample sizes have traditionally been very small and Whittington and Podd (1996) identified this fact in a power analysis of human MF experiments. Some later studies have attempted to address this issue by using sample sizes between 70 to 100 (Kazantzis et al., in press; Whittington et al., 1996). Whittington, et al. (1996) proved the value of larger than normal sample sizes by randomly selecting varying numbers of participants from the total sample size of 100 used in the study. A sample size of 75 participants was required before the effect of MF exposure on RT was detected. Smaller sample sizes of 25 and 50 participants did not produce a significant result, even though an effect truly

existed. The present study therefore used a large sample size in order to increase statistical power. Unfortunately, despite a reasonably large sample size of 80 participants, the use of a between subjects design meant that for each exposure condition (sham and real) there was really only a sample size of 40. Therefore, an effect may have existed when a null result was found but statistical power was not high enough to detect it. For example, the test of the interaction between Field and Block on the measure of RT only had SP of 0.44.

In psychological research a conventional alpha level of 0.05 has traditionally been used. It has been noted that the use of such a stringent alpha level is not appropriate in every situation and especially not in the MF research arena where effect sizes are expected to be small (Whittington & Podd, 1996; Podd, Page, Rapley, & Beale, 1998). If the alpha level is not relaxed, power may remain low and an increased likelihood of type II errors exists. In the early stages of a research program where it is likely that ESs are small, type I and II errors are equally important and neither one should be accorded more emphasis. The power to detect small or medium effects must be present for research to produce any meaningful results and relaxing the alpha level is one way of directly achieving this. However, despite the relatively large number of participants and relaxed alpha level of 0.30, insufficient power was available for some of the statistical tests. For example, the statistical power to detect any main effect of a MF on PC and RT during the visual duration discrimination task was only 0.44 and 0.30 respectively. These values are too low for any certainty to be placed in the obtained null results. However, sufficient statistical power was available for testing the effects of MF exposure on



recognition memory. The medium effect sizes found for measures of both PC(memory) and confidence (0.26 and 0.23 respectively) combined with the relaxed alpha level of 0.30 produced respective statistical power levels of 0.90 and 0.85.

The present recognition memory finding can be used to illustrate these points (i.e. reducing sample size). If only half the number of participants had been run (20 in sham and 20 in real, with an alpha level of 0.05) the effects of the MF on recognition memory would not have reached significance, because the statistical power of the test would have been considerably lower. Unfortunately, despite the relatively large participant numbers, the present study still lacked sufficient statistical power to detect very small ESs. Adequate power could have been achieved if more participants had been used but practical limitations did not allow for this. However, future research could conduct such a study and combine it with the present results with the aim of developing a useful, meaningful set of conclusions. Without sufficient statistical power, research is rather pointless as no firm conclusions can be reached regarding null effects.

### ***Future Research***

The null effects observed in the present study are open to interpretation and are by no means conclusive. Only a handful of studies have been conducted on the effects of weak ELF MFs on human performance measures. The null MF effects on performance

measures during a visual duration discrimination task may have been confounded by the use of only a hard task, and possibly an increase in the number of trials. It is highly recommended that exact replication studies of both the Whittington et al. (1996) study and the present study be carried out. In this way, valid comparisons with Whittington et al., could be made and MF-induced decrements in RT could be either supported or disclaimed. Replication studies of the present experiment would aid in the achievement of adequate statistical power regarding MF effects on RT. In addition, the available knowledge pertaining to MF-induced effects on RT could be extended.

Future research supporting the present findings on the visual duration discrimination task would suggest that measures of RT over a large number of solely difficult trials are not sensitive to MF exposure effects. To clarify the role of varying levels of task difficulty within the same experimental session, a study could separate participants into two groups. One group could complete two sessions of 150 visual duration discrimination trials varying between three levels of difficulty under sham and exposure conditions as in the Whittington et al. (1996) study. A second group could complete two sessions of 50 trials at only the hard difficulty level under sham and exposure conditions. If there is no significant difference between performance on the 50 hard trials in Group 1 and the 50 hard trials in Group 2, then the inclusion of easier trials has no effect on outcome. Therefore, any null RT results obtained through the testing of only a hard visual duration discrimination task can not be accounted for by the absence of easier trials.

The results from the present study support future research into the effects of MF exposure on memory, specifically recognition memory. The findings suggest that measures of recognition memory may be sensitive to the delayed effects of MF exposure and further investigation could include exposure to a MF throughout the entire recognition memory task, not just the retention interval. Additionally, future research could investigate memory more broadly in relation to the effects that MFs have on it. For example, MF effects on recall could also be studied, and the presence of the MF could be varied (some participants exposed during only the study phase, the retention phase or the test phase, for example).

As no previous MF research has focused investigation on recognition memory, the present study has broken new ground. Therefore, it is extremely difficult to evaluate and interpret such findings until similar research is conducted and theories are formulated. Subsequent examination into the effects of MF exposure on human performance should seriously consider the inclusion of recognition memory measures in light of the present findings.

In the present study, statistical power was still inadequate during the visual duration discrimination task despite the use of techniques to improve it. Future research needs to remain focused on the issue of statistical power using any technique available to increase design sensitivity. Large sample sizes are an obvious but not always practical approach to increasing power. Ideally, research should run as many participants as necessary to achieve a desired level of power, but the cost and time involved in doing so often makes

this impractical. Schmidt (1996) highlights the fact that very rarely does one study answer the question it set out to resolve and meta-analyses is considered a possible solution to this problem. Meta-analyses combines the findings of independent studies in order to reach a conclusion and the magnetic field research arena would benefit greatly from the increased use of this statistical method.

### *General Conclusion*

In the present investigation, measures of RT and PC during a difficult visual duration discrimination task were found to be unaffected by exposure to an intermittent ELF MF. This result fails to support the observed slowing of RT during the same visual duration discrimination trials under field exposure conditions in the Whittington et al. (1996) study. However, low statistical power and differences in experimental parameters make direct comparison between the present study and Whittington et al.'s study difficult. A delayed MF effect was, however, found on a recognition memory task. Decrements in both recognition memory and decision confidence were observed when participants had been previously exposed to the ELF MF. Such findings highlight a need for further research into MF effects on memory performance. The demand for increased attention on statistical power in future studies has also been highlighted.

At present, research on the effects of weak ELF MFs on biological systems is focused mainly on simple data collection. Although theories have been developed to explain

how MFs may interact with, or are sensed by biological systems, none are considered to be adequate. Research into the effects of MFs is in great need of direction and this will only come with the development of strong, testable theories of how weak ELF MFs are able to affect human performance. Critical studies would then be aimed at supporting or refuting these theories and progress would be made. Nonetheless, the MF research arena is still relatively new and there is a shortage of data on the effects of MFs on biological systems, especially on humans. Thus, there is a demand for many more data-collecting studies to broaden our knowledge of MFs and their effects. Ultimately, it may be that the theories so badly needed arise from further investigations such as the present study.

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## **Appendix A**

This appendix contains:

The screening questionnaire

The information sheet

The consent form

# THE EFFECTS OF MAGNETIC FIELDS ON HUMAN PERFORMANCE

## PARTICIPANT SCREENING QUESTIONNAIRE

Please answer the following questions by writing "Yes" or "No" next to each. Do not hesitate to ask if something is not clear.

1. Have you previously participated in magnetic field research?
2. Are you pregnant?
3. Have you any chronic health problem?
4. Have you any cardiovascular problems?
5. Have you a history of brain or nervous system damage or disorder, such as epilepsy?
6. Have you had an illness which has confined you to bed for more than 3 days in the past 3 months?
7. Are you currently undergoing psychotherapy, or are you contemplating such treatment?
8. Are you taking any medication?
9. Do you have any dietary restrictions or unusual dietary habits?
10. Do you wear any form of metal prosthesis, or do you have implanted any metal or electronic devices such as a cardiac pacemaker?

# THE EFFECTS OF MAGNETIC FIELDS ON HUMAN PERFORMANCE

## Information for Participants

The principal researchers for this study are Jeana Abbott (Department of Psychology) and Dr John Podd (Department of Psychology). Jeana Abbott can be contacted through the Department of Psychology or at her home number, (06) 374 1595. Dr Podd can be contacted at work, phone 350-4135 or at his home, phone 357-3490.

Everyday we are surrounded by and exposed to weak magnetic fields such as those produced by electric toasters, lights, televisions etc. We are conducting this study to help discover whether magnetic fields affect human performance. The present study will assess the effect of a weak magnetic field on recognition memory and visual discrimination.

There are three parts to this study. First, you will be asked to watch 40 visual shapes presented one after the other. During the second part, you will be asked to watch as two lights flash, and respond by indicating which flash was longer. You will be asked to do this about 225 times (including 25 warm-up and practice trials). You will be positioned between two large copperwire coils which will have an electric current passed through them. This current generates the magnetic field. In the third part of the study, we will ask you to complete a recognition test. On each trial, you will be shown two shapes. Your task will be to pick out the shape you were shown earlier, and rate your confidence in your decision. The magnetic field will be switched on only for the task involving the light flashes, not for the memory task.

The total experimental time is about 30 minutes and you could expect the whole session to be complete in 35-40 minutes. The extra time over and above the experimental time is to introduce you to the study, to transfer you between different phases, and for you to ask any questions.

You will no doubt be aware of the current interest in the possibility that weak magnetic fields may affect human behaviour, albeit in very small ways. In return for your participation in our study, we will be very willing to tell you as much as we can about magnetic fields and why they interest us so much.

The field strengths we are concerned with are of the same order of magnitude as those produced by electrical appliances in your home, such as those mentioned above. The field strength we are using is well within the limits of exposure set by the Department of Health National Radiation Laboratory, and those set by the International Radiation Protection Association. Therefore, by current standards, the magnetic fields you would be exposed to, should you participate, are not harmful.

If you agree to take part in our study, you have the right to:

- \* Refuse to answer any particular question we might ask.
- \* Withdraw from the study at ANY time.
- \* Ask any questions you may have at any time during your participation.
- \* Provide information on the understanding that it is completely confidential to the researchers. All information is collected anonymously, and it will not be possible to identify you in any reports prepared from the study.
- \* Be given access to your own personal data, and a copy of it if you want it.
- \* Be given access to a summary of the findings from the study when it is concluded.

Our everyday environments are often filled with low intensity magnetic fields and the questions constantly asked are can they affect our behaviour, even in small ways, and if so, how do these fields affect us? We hope that you will be willing to take part in our study to help us get closer to finding the answers to such questions.

**Jeana Abbott (Department of Psychology, or (06) 374 1595)**  
**Dr John Podd (Department of Psychology, Extn 4135, or 357-3490)**

# THE EFFECTS OF MAGNETIC FIELDS ON HUMAN PERFORMANCE

## CONSENT FORM

I have read the Information Sheet for this study and have had the details explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I also understand that I am free to withdraw from the study at any time, or to decline to answer any particular questions in the study. I agree to provide information to researchers on the understanding that it is completely confidential.

I wish to participate in this study under the conditions set out in the Information Sheet.

Signed: \_\_\_\_\_

Name: \_\_\_\_\_

Address: \_\_\_\_\_

Phone: \_\_\_\_\_

Gender: \_\_\_\_\_

Age: \_\_\_\_\_

Date: \_\_\_\_\_

## **Appendix B**

This appendix contains:

The recognition memory test sheet

The FSQ

## MFs and RECOGNITION MEMORY

OLD SHAPE			CONFIDENCE				OLD SHAPE			CONFIDENCE			
			very sure	sure	not so sure	unsure				very sure	sure	not so sure	unsure
0.	L	R	1	2	3	4	20.	L	R	1	2	3	4
1.	L	R	1	2	3	4	21.	L	R	1	2	3	4
2.	L	R	1	2	3	4	22.	L	R	1	2	3	4
3.	L	R	1	2	3	4	23.	L	R	1	2	3	4
4.	L	R	1	2	3	4	24.	L	R	1	2	3	4
5.	L	R	1	2	3	4	25.	L	R	1	2	3	4
6.	L	R	1	2	3	4	26.	L	R	1	2	3	4
7.	L	R	1	2	3	4	27.	L	R	1	2	3	4
8.	L	R	1	2	3	4	28.	L	R	1	2	3	4
9.	L	R	1	2	3	4	29.	L	R	1	2	3	4
10.	L	R	1	2	3	4	30.	L	R	1	2	3	4
11.	L	R	1	2	3	4	31.	L	R	1	2	3	4
12.	L	R	1	2	3	4	32.	L	R	1	2	3	4
13.	L	R	1	2	3	4	33.	L	R	1	2	3	4
14.	L	R	1	2	3	4	34.	L	R	1	2	3	4
15.	L	R	1	2	3	4	35.	L	R	1	2	3	4
16.	L	R	1	2	3	4	36.	L	R	1	2	3	4
17.	L	R	1	2	3	4	37.	L	R	1	2	3	4
18.	L	R	1	2	3	4	38.	L	R	1	2	3	4
19.	L	R	1	2	3	4	39.	L	R	1	2	3	4

## FIELD STATUS QUESTIONNAIRE

1. In your judgement was the field on or off during the visual discrimination tasks?: (Please circle your decision)

ON / OFF

2. How confident are you in this judgement?:  
(Please circle your decision)

1	2	3	4
very sure	sure	not so sure	unsure



## APPENDIX C

This Appendix contains:

Prerecorded audio instructions presented to participants at the beginning of  
the experimental session

Computerized instructions for the study phase of the recognition memory  
task

Prerecorded audio instructions for the visual duration discrimination task

Computerized instructions for the test phase of the recognition memory task

*Prerecorded participant instructions for the beginning of the experimental session*

Hi, what follows are standardized instructions. The experiment you have kindly offered to participate in involves three parts. In part one, you will view 40 shapes which you must try to commit to memory. In part two you will complete 25 practice trials of a visual discrimination task followed by 200 experimental trials in which you will be exposed to a weak magnetic field. There will be a short break in this part. Finally, in part three you will be asked to complete a memory recognition test regarding the shapes you saw in part one. You will only be exposed to the MF during the experimental trials in part two.

Part one will now begin. You are about to be shown 40 individual shapes. Each shape will be presented for three seconds. Please concentrate and try to commit each shape to memory.

*Computerized participant instructions for the recognition memory study phase*

Page 1

NonVerbal Recognition Memory Task

This task was developed by  
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for a project by Jeana Abbott

Department of Psychology,  
Massey University, 1997

Instructions will follow

Page 2

This task consists of two parts:

- 1) In the first part you will see abstract drawings presented one at a time in the middle of the screen.

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- 2) In the second part you will see pairs of drawings. One drawing will be from the first part (an old drawing), the other will be new. You will be asked to choose which drawing is old.

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You will receive further instructions before each of these two parts. You will also get a chance to practice the task. During practice, numbers will be used instead of drawings.

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You will shortly be presented with a series of abstract drawings to study and remember. Your task later will be to identify which has been seen. Do you have any question?

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Please watch the drawings carefully and do your best to remember them.

**\*PRESENTATION OF 40 SHAPES\***

Page 7

You have finished the study phase. After the visual discrimination tasks you will be asked to remember the shapes you have just seen.

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Task in Pause Mode

*Prerecorded participant instructions for the visual duration discrimination task*

The two coils near your head are used to generate the MF. You have been assigned to a group in which the field will always be on during the discrimination task. There is no need for you to touch the coils, but should you do so accidentally they will not harm you because the current passing through them is very weak.

First you will begin by completing 25 practice trials of a visual discrimination task. You will then complete 200 experimental trials in the presence of a low intensity MF. Please place your left forefinger on button one and your right forefinger on button two. Now concentrate on the small red light directly in front of you. Shortly, a warning tone will sound after which the light will flash twice. Your task is to decide which flash was longer in duration.

If you believe the first flash was longer, press button one. If you believe the second flash was longer, press button two. Please respond as accurately and quickly as you can. The lights will flash very quickly making each trial very difficult. Please persevere and guess when uncertain. Each trial is completely independent of the other, so don't press button one just because you have pressed button two on the last three trials. Remember, you have to decide which flash is longer in duration.

Shortly after your response the warning tone will sound again indicating the next trial.

At times your eyes may tire or become blurred. Please try to continue as accurately and

quickly as you can. After about five minutes there will be a short rest. The remaining half of the trials will then be completed. Remember, you have the right to withdraw from the study at any stage. Are there any questions?

*Computerized participant instructions for the recognition memory test phase*

Page 9

Would you like to complete  
a set of practice trials?

Press the appropriate key of  
Y = Yes      N = No

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This section is provided to give you  
practice at answering on the paper  
provided. In this practice you will  
not have to complete the study phase.

Page 11

You will see a pair of numbers  
presented side by side on the  
screen. One number will be old, the  
other will be new. Your task is  
to decide which number is old.

Page 12

If you think the number on the left  
is old, circle the "L" option on the  
paper provided. If you think the  
number on the right is old, circle  
the "R" option.

Page 13

Please respond by circling "L" or "R"  
as soon as you have made your decision.  
The small number appearing in the  
top left of the screen is to identify  
the current trial number.

Page 14

After making your response, please rate how confident you are that decision is correct on the paper provided.

Page 15

To rate your confidence, you will have four choices:

- 1 - Very Sure
- 2 - Sure
- 3 - Not so sure
- 4 - Unsure

Page 16

You are about to begin, do you have any questions?

\* PRESENTATION OF SIX PRACTICE TRIALS \*

Page 17

Would you like to complete another set of practice trials?

Press the appropriate key of  
Y = Yes      N = No

Page 18

You have finished your practice. Your next task will be to identify the abstract drawing previously studied.



Page 19

You will now be presented with pairs of drawings side by side on the screen. If you think the drawing on the left is old, circle the "L" option. If you think the drawing on the right is old, circle the "R" option.

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Remember to rate how confident you are in this decision. Please circle the appropriate response on the 4-point scale.

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You have 6 seconds to make your response. Try to be as accurate as you can, but guess if you have to.

Page 22

You are about to begin, do you have any questions?

\* 40 EXPERIMENTAL TRIALS \*

Page 23

Congratulations, you have completed the nonverbal recognition memory task.

## **APPENDIX D**

This Appendix contains:

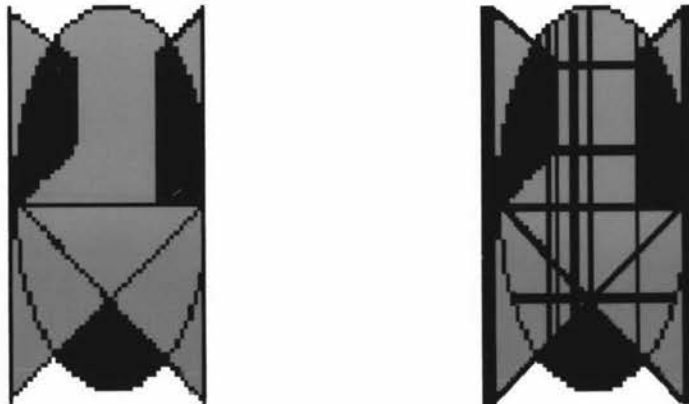
Abstract shapes used in the recognition memory task

*Abstract shapes used in the recognition memory task.*

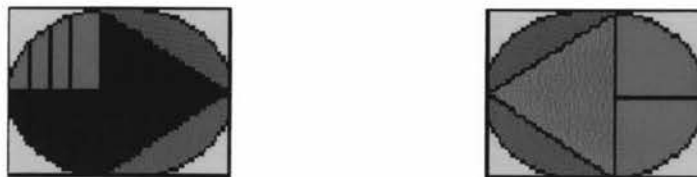
For the recognition memory task, participants were required to view individual abstract shapes during the study phase. During the test phase participants completed 2AFC trials in which they had to indicate which of two presented abstract shapes they had seen previously. During the test phase, each target stimulus was paired with a distractor shape. Each distractor was similar in appearance to the target stimulus but contained differences such as additional lines, different colours and so on.

Two examples of a recognition memory test trial are presented below. In example (a) the target stimulus was on the left side and in example (b) the target stimulus was on the right side.

(a)



(b)



## **APPENDIX E**

This Appendix contains:

Access to Raw data

***Access to raw data***

Due to reformatting and the extensive nature of the raw trial by trial data for both tasks, they have not been included. However, a full copy can be obtained by contacting Dr John Podd.

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